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## ORIGIN OF THE PEGMATITES OF MAINE[1]

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During a portion of the summers of 1906 and 1907 I had the opportunity to study in some detail the pegmatite deposits of Maine, and at intervals during succeeding years have been able to pay brief visits to commercially important pegmatite deposits in Connecticut, New York, Pennsylvania, and Maryland. Without entering into the details of the field occurrences, which will be described in a forthcoming bulletin of the U.S. Geological Survey, I wish to summarize here the more important scientific results of these studies. Particular acknowledgment is due to Dr. Whitman Cross of the U.S. Geological Survey, for valuable criticism and advice in this work.

The pegmatite deposits in the state of Maine all belong to the type commonly known as granite pegmatite, its dominant minerals being the same as those which are most abundant in ordinary granites. Pegmatites are most abundantly developed in the western and southwestern part of the state, and are invariably associated with granites. Excellent exposures in the feldspar and gem quarries, on glaciated ledges, and especially along the seashore in the Boothbay Harbor region, afford unusual opportunities for detailed field studies.

*General geologic relations.*—The pegmatite masses vary in size from extremely small stringers intimately injected between the foliae of schists and thus forming injection gneisses, to batholitic masses

[1] Published with the permission of the Director of the U.S. Geological Survey.

a mile long and one-half mile wide, showing coarse pegmatitic textures throughout. Most commonly the pegmatite masses are roughly lens-shaped and lie parallel to the foliation of the inclosing schistose rocks, their attitude being dikelike or sill-like, according as the schists lie at steep or gentle inclinations.

The rocks associated with the pegmatites are granite gneiss, granites of various textures, and schists of sedimentary origin. The field relations show that the pegmatites are invariably intrusive into the sedimentary schists, frequently cutting sharply across the schist foliae though usually intruded parallel to them. Characteristic contact metamorphic minerals are sometimes developed. Into the granite gneisses the pegmatites are also in some instances distinctly intrusive, but in other cases their relations indicate that the two rocks are nearly contemporaneous and probably related in origin.

The relations between the pegmatites and the granites indicate beyond reasonable question that the two rock types are genetically related. Evidence of this is found (1) in the fact that the predominant minerals in both rocks are the same; (2) in the occurrence of granite in all districts where pegmatites are found, and (3) in numerous observed instances of transition from granite to pegmatite. One of the most instructive instances illustrating such transition is exposed on the shore of Boothbay Harbor, and is illustrated in Fig. 1. Microscopic examination of the fine-grained granite and the pegmatite in this occurrence shows that the mineral species in the two rocks are identical, the sole differences being in the texture and the proportions of the constituents. In other instances small irregular segregation-like masses with pegmatitic texture are wholly inclosed by normal granite. Although in certain instances distinct dikes of pegmatite cut the granites and in other instances dikes of granite cut the pegmatites, there is no evidence that the two rocks are of widely different ages or that there was more than one general period of granite and pegmatite intrusion. The granites are known to be of late Silurian or early Devonian age, and it is probable that the pegmatites are to be similarly correlated. With the exception of certain diabases, the granites and pegmatites are the youngest known igneous rocks of the state.

*Mineral composition and texture.*—As already stated, the dominant

pegmatite minerals are those characteristic also of the normal granites; namely, quartz, orthoclase and microcline, albite or oligoclase, muscovite, biotite, and black tourmaline. Accessory constituents nearly always present are garnet, magnetite, and green opaque beryl. Accessory minerals which are present only in certain pegmatites number

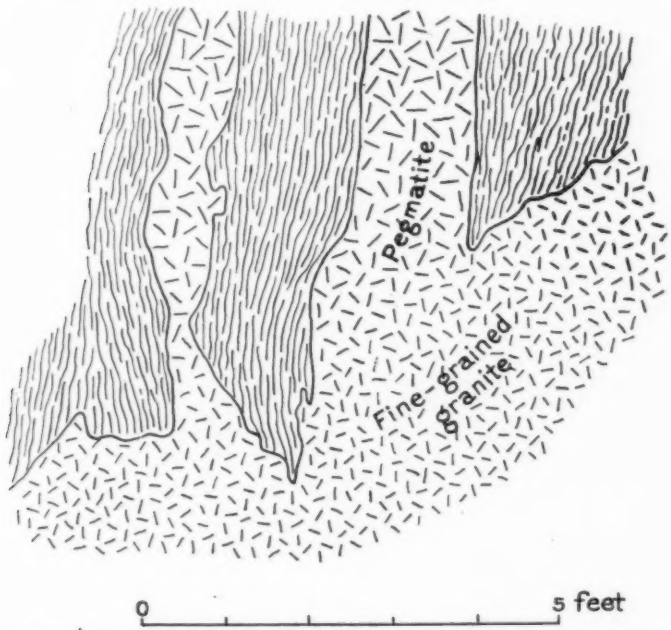



FIG. 1.—Granite grading into pegmatite and both intrusive in schists. Shore of Southport Island near south entrance of Townsend Gut.

over fifty species; the most important are lepidolite, amblygonite, spodumene, blue, green, and pink tourmaline, transparent blue, green, or golden beryl, colorless to amber-colored topaz, and rose and amethystine quartz. A number of pegmatites have been successfully worked for certain of these gem minerals.

In possibly ninety-nine one-hundredths of the pegmatite masses in the state no unusual minerals are present, the constituents being the same as in the normal granites and the proportions also somewhat

similar. The principal variations in composition involve (1) an increase in silica, (2) an increase in sodium and lithium, and (3) an increase in fluorine. The increase in silica content manifests itself in a greater abundance of quartz. Pegmatites unusually rich in quartz are less common in Maine than in certain other pegmatite districts of the eastern United States, but it is quite possible that many of the quartz dikes occurring in southern Maine were derived from pegmatite

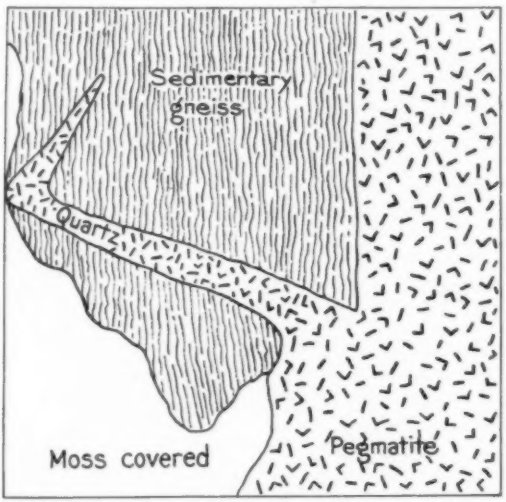



FIG. 2.—A quartz offshoot from pegmatite, 2½ miles northeast of Paris. The branch vein is pegmatite for a short distance beyond the main pegmatite mass, but beyond this grades into pure quartz. The area illustrated is about 4 feet square.

magmas. This is suggested by the fact that certain of these masses contain occasional crystals of feldspar, black tourmaline, or beryl. In one instance, the transition from pegmatite to quartz vein, illustrated in Fig. 2, was observed. The second variation, involving an increase of sodium and lithium, shows itself in the development of occasional pegmatite masses which are rich in albite, lepidolite, spodumene, colored tourmaline, and amblygonite. The tourmaline mines of the state are in deposits of this type. The third variation, involving an increase in the fluorine content, is exemplified by occasional pegmatite masses which contain topaz, fluorite, herderite, hamlinite,

certain types of apatite, etc. Increase either in sodium and lithium or in fluorine is usually accompanied by an increase in phosphorus content. The pegmatite characterized by these rarer minerals constitutes only an exceedingly small part of the total volume of pegmatite in any district.

In coarseness, the pegmatites vary from little coarser than normal granites to masses showing single crystals of feldspar 20 feet across. Their distinguishing feature is therefore not coarseness but extreme irregularity of grain. Distribution of the constituent minerals in bands, such as is observed in pegmatites in some other regions, is entirely absent in Maine, the minerals usually (except for the graphic intergrowths) being distributed with complete irregularity. Graphic intergrowths are very abundant and include those of quartz with feldspar and less frequently of quartz with muscovite, feldspar with muscovite, garnet with quartz, black tourmaline with quartz, and spodumene with quartz. All of these intergrowths may occur in the same pegmatite mass.

Cavities are practically absent from the finer-grained pegmatites, and in most of the coarse-grained pegmatites constitute less than 1 per cent of the total volume. The gem-bearing pegmatites, however, are usually characterized by a central zone in which albite, lepidolite, tourmaline, amblygonite, etc., are particularly abundant and in which miarolitic cavities are also quite abundant. It is on the walls of such cavities that the gem tourmalines were developed. At Mt. Mica, which is the largest and most famous tourmaline locality in Maine, the largest pocket found was $20 \times 12 \times 7$ feet, but the majority do not average more than a foot or two in diameter. Only a few of these pockets contain gem minerals in any considerable amounts, but groups of quartz crystals are developed on the walls of many others.

*Origin.*—The writer does not purpose in this article to attempt a discussion of the voluminous literature on pegmatites except in so far as it bears closely upon those of the region under discussion. Previous writings and theories have been well summarized by George H. Williams[1] and especialy by Brögger.[2]

[1] George H. Williams, *Fifteenth Ann. Rept. U.S. Geol. Survey*, 675–84.

[2] Brögger, "Der Syenitpegmatitgange der südnorwegischen Augit und Nephelinsyenite," *Zeitschr. f. Kryst.*, XVI (1890). Sections on genesis translated in *Canadian Records of Science*, VI (1894), 33–46, 61–71.

If, as seems necessary from the field evidence, we admit a genetic connection between the pegmatites and granites, it is next of importance to inquire what evidence is afforded by the Maine pegmatites as to the physical and chemical conditions which resulted in the crystallization, from related magmas, of rocks of such widely varying character.

*Influence of external conditions.*—Differences in external conditions at the time of crystallization appear inadequate to explain the observed textural differences. This is shown by the close associations of the two types of rocks, already cited as evidence of their genetic relationships. The field relations show that in many instances the external conditions, such as the nature and temperature of the wall-rock, depth at which solidification took place, etc., were similar for both types of rocks. In cases, such as shown for example in Fig. 1, the general external conditions must have been practically the same for both rocks. A similar conclusion is justified in numerous other instances where granite and pegmatite grade into each other and especially in cases where pegmatite forms segregation-like masses wholly inclosed in granite. Conversely, the broad general similarity of the pegmatites over very large areas where the external conditions were certainly *not* constant also indicates that the causes of their peculiar textures were in the main internal rather than external. It seems necessary to look therefore to differences inherent in the magmas themselves for an explanation of the textural variations.

*Influence of dominant constituents.*—The characters shown by the Maine pegmatites accord with the evidence obtained from many other districts in indicating that the pegmatite magma were characterized as a general rule by the presence of certain components in larger amounts than in normal granite magmas and that these differences in composition were in large measure responsible for the differences in texture. The exact nature of such differences is, however, more largely a matter of inference than of direct field observation.

In the great mass of the pegmatite, what may be termed the *normal* pegmatite, it is exceedingly difficult, if not impracticable, to make a satisfactory estimate of the relative proportions of the different mineral constituents, but as far as can be judged without measurements the proportions are of the same general order as in the normal granites,

except that the pegmatites are probably on the average slightly more quartzose, a conclusion which seems warranted by the frequent transitions from pegmatite masses into veins composed largely or wholly of quartz. As is well known, the highly quartzose types show as typical pegmatitic textures as the less quartzose. The difference in the proportions of the *principal* mineral constituents in the normal granites and the normal pegmatites seems, therefore, insufficient to account for the great difference in their textures. It appears necessary to seek the cause of these contrasts in differences in the proportions of minor constituents or in the presence in the granite or pegmatite magmas of constituents which have since escaped, or which through occlusion are not now visible to the unaided eye, in the derived rocks.

*Influence of minor constituents.*—The presence in many pegmatites of unusual minerals, such as fluorite and other fluorine-bearing minerals, lithium minerals, boron and phosphorus minerals, and occasionally the rare earth minerals, has led certain geologists[1] to attribute to some of these substances an important rôle in the production of pegmatite textures. It cannot be doubted that when present in magmas such substances have some influence upon the texture of the resulting rock. It has not been demonstrated however that the presence of these unusual constituents is essential to the development of typical pegmatitic textures. In the opinion of the writer their presence is probably *not* essential. The pegmatites which earliest attracted the attention of American mineralogists and geologists and which have been most often described in the literature were naturally those in which unusual minerals were present in especial abundance or in perfection of crystal form. Such pegmatites constitute, however, only an exceedingly small proportion of the pegmatite in any district and must be regarded as unusual rather than normal types. The writer is familiar with certain deposits showing typical pegmatitic textures, which have been worked for their feldspar for years with the discovery of few if any of the rarer minerals.[2] In the great majority of the pegmatites of Maine unusual minerals are of

[1] Certain French geologists in particular have been advocates of this view. See De Lapparent, *Traité de géologie*, 4th ed., 639 (1900); and De Launay, *La science géologique*, 557–58, 582–83 (1905).

[2] The Andrews feldspar quarry in Portland, Conn., the Frost feldspar quarry in Maryland, and the Goldings feldspar quarry in Georgetown, Maine, are examples. See *Bull. U.S. Geol. Survey No. 420*, 31, 50, and 75.

such infrequent occurrence as ordinarily to escape detection entirely. In pegmatities where they are present their paucity or abundance seem to have small influence on the textures developed. Those inclined to attribute large influence in the development of pegmatitic textures to the presence of rare constituents usually contend that a more careful study will show that their scarcity is apparent rather than real. Such an assumption is not in accord with the field observations of the writer in Maine and other parts of New England, and appears unwarranted.

*Influence of gaseous constituents.*—If neither the dominant nor the rare minerals of the pegmatites have been controlling factors in the development of typical pegmatitic textures, it appears necessary to seek an explanation in the presence in the magmas of certain constituents which have subsequently escaped or at least are not readily recognized in the resultant rock. The fact that large crystals cannot be obtained at atmospheric pressures from simple dry melts of the commoner rock-forming minerals suggests at once that the crystallization of these minerals in nature took place either under widely different physical conditions (such as high pressure) or in the presence of certain substances which are scarce or absent in the rocks as now exposed. It has already been shown from field evidence (p. 302) that in many instances differences in pressure or other external conditions at the time of crystallization cannot reasonably be appealed to, to explain the textural variations observed. In such cases an appeal to the escaped constituents of the magma appears unavoidable. The same conclusion appears necessary when we consider the extreme viscosity exhibited (under atmospheric pressures) by silica, orthoclase, and albite near their melting temperatures. The various forms of silica which have been artificially produced have all crystallized from a melt so viscous as to be virtually a glass.[1] In the case of orthoclase the viscosity of its melt is so great that all attempts to crystallize the mineral from it have been unsuccessful. Since increase in pressure *per se* can hardly be appealed to as increasing molecular mobility[2]

[1] See Day and Shepherd, "The Lime-Silica Series of Minerals," *Amer. Jour. Sci.*, XXII, 271–73 (1906). Also Day and Allen, "The Isomorphism and Thermal Properties of the Feldspars," *Publications of the Carnegie Institution of Washington No. 31*, 28–29, 45–55 (1905).

[2] See Harker, *The Natural History of Igneous Rocks*, 163–64 (1909).

in magmas, it seems necessary again in accounting for the large crystals developed in the pegmatites to postulate the presence in the magma of some substance or substances not now recognizable in the derived rock. That the presence of volatile constituents in a magma does influence the viscosity is shown by the fact that certain obsidians may be readily melted with evident fluidity and the escape of gases, but that their refusion after such gases have escaped is much more difficult. Prof. Iddings[1] has also shown from a microscopic study of the obsidian of Obsidian Cliff, Yellowstone National Park, that where there was more dissolved gas the conditions were more favorable for crystallization than in other parts of the magma.

Among those constituents of magmas which might escape, leaving little record of their former presence, water gas and hydrogen are probably the most abundant, as is plainly indicated by analyses of the gases still remaining in igneous rocks[2] and by studies of the gases emitted from volcanic vents.[3]

The presence of water gas in association with subordinate amounts of other gases and of certain unusual substances (mineralizers) has been considered by many observers to be the competent and effective cause in the development of pegmatitic textures. With this opinion the present writer is in general accord, though the persuasion is based more largely upon the process of reasoning already outlined than upon field evidence of high water content or relatively low viscosity in pegmatite magmas. The field evidence gathered in the study of the Maine pegmatites must be looked upon as merely suggestive; anything like a complete solution of the problem will in all probability wait upon synthetic laboratory experiments upon the interaction between gases and rock-forming silicates.

The small weight of the gaseous and liquid constituents of most igneous rocks as compared with the total weight of the rock might lead one to question their competence to affect notably the viscosity

[1] J. P. Iddings, *Seventh Ann. Rept. U.S. Geol. Survey*, 283–87 (1888); *idem*, *Igneous Rocks*, 185 (1909).

[2] See R. T. Chamberlin, "The Gases in Rocks," *Publications of the Carnegie Institution of Washington No. 106* (1908). This includes a summary of earlier investigations.

[3] For a review of the literature on volcanic gases, see Clarke, "The Data of Geochemistry," *Bull. U.S. Geol. Survey No. 330*, chap. viii (1908).

of magmas and to produce large textural variations. In this connection it may not be out of place to call attention to a possible application of Raoult's Law.[1] This law states that if various substances are dissolved in equal amounts of the same solvent in the proportions of their molecular weights the resulting lowering of the freezing-point of the solution will be the same in each case.[2] In other words the effect produced is a function of the number of molecules concerned and is not primarily dependent on the nature of the substances introduced. It follows that a small amount by weight of a substance of low molecular weight (such as $H_2O$, mol. wt. 18) will exert the same depressing influence on the freezing-point of the solution as a much greater weight of a substance of high molecular weight (such as $Fe_2O_3$, mol. wt. 160), and that given equal weights of the two, the substance of low molecular weight will exercise much the greater influence. This law has been found to apply strictly only to very dilute solutions where there is no chemical action between solvent and dissolved substance. It has been applied bodily by Vogt[3] to rock magmas, but the wisdom of such extension to cover widely different and much more complex physical conditions may well be questioned. It seems not unreasonable, however, to attribute some general importance to this principle in rock magmas, to the extent that magmatic constituents of low molecular weight may exert greater influence in lowering the freezing-point, decreasing viscosity, and affecting textures than constituents of high molecular weight. They may thus attain an importance which appears disproportionate to the small part by weight which they form of the whole magma. The substances (hydrogen, water, fluorine, chlorine, and boron) commonly believed to exert the greatest influence upon the viscosity of magmas and the textures of the resulting rocks are all substances of much lower molecular weights than silica and the rock-making silicates and oxides, even when the minimum values for the latter are assumed. The hiatus between the molecular weights of these two groups of substances is so marked as to justify the retention of the term "mineralizers" for the lighter group, in case the

[1] See Ostwald, *Outlines of General Chemistry*, 136–37 (1895).

[2] Neglecting electrolytic dissociation, which is probably of small importance in rock magmas.

[3] See Vogt, *Die Silikatschmelzlosungen*, II, 128–35 (1904).

principle outlined above is eventually shown to be operative to an important degree in magmas. It is perhaps unnecessary to add that other causes besides low molecular weight may be effective in reducing viscosity in magmas.

*Field and laboratory evidence bearing upon viscosity and gas content.*—The field and laboratory data on the pegmatites of Maine which bear upon the viscosity or gaseous content of the pegmatite magmas may be set forth as follows. Since the pegmatite magmas crystallized at some distance below the surface, the gases which they contained must either have made their escape through the wall-rocks or else have remained in cavities or occluded within the solid pegmatite mass. The escape of such materials through the wall-rocks should presumably leave some record in contact metamorphic effects. Their retention within the rock should presumably be recorded in an especial abundance of miarolitic cavities and fluid or gaseous inclusions. The field studies of the writer in Maine and other parts of New England show that the granites are almost wholly devoid of miarolitic cavities of any kind. An isolated cavity of small size is occasionally met with but its walls are usually more or less pegmatitic in texture. In the great bulk of the pegmatites of Maine, particularly the finer-grained ones, such cavities are also exceedingly rare. In the coarser pegmatites, however, they are a characteristic feature, though usually, as far as can be judged, constituting considerably less than 1 per cent of the total volume of the pegmatite. Within the very limited gem-bearing zones of certain pegmatites miarolitic cavities may form a considerably larger percentage of the total volume. Such cavities have been attributed by various writers to shrinkage of the pegmatite mass in crystallization. This may in fact play some part in their formation but that they are not entirely the result of shrinkage but on the contrary were filled or partly filled with some material which has since disappeared, is shown by the presence of perfectly developed crystals of quartz, tourmaline, and other minerals projecting inward from the walls of the cavities. Some filling must have been present from which such crystals derived the materials for their growth. It is probable therefore that immediately after the crystallization of the main body of pegmatite the miarolitic cavities were completely filled with a gaseous solution which may later have liquefied and has since

disappeared. Water gas probably formed the bulk of this cavity filling, though carrying numerous other substances in solution. The abundance of quartz crystals on the walls of these cavities indicates that silica was one of the most abundant of these dissolved substances.

If the presence of larger amounts of gaseous constituents is responsible for the crystallization of the rock with pegmatitic rather than granitic texture, we might reasonably expect greater size or abundance of microscopic fluidal or gaseous cavities in the pegmatite minerals than in those of the normal granites. With this idea in mind the writer attempted a microscopic measurement of these inclusions in pegmatites and associated granites from Maine. On account of the uneven distribution of the inclusions in bands traversing the minerals accurate estimates were found to be impracticable and the results were negative or inconclusive. It was found moreover that some of the bands of fluidal cavities in the quartz of pegmatite were formed later than shearing movements which had affected the quartz. The inclusions in the pegmatite were similar in character to those in the normal granites of Maine, and any differences in their size and abundance in the two types of rocks were not sufficient to be noted on casual inspection.

If the pegmatite magmas are characterized by considerably larger proportions of gaseous constituents than are present in the granite magmas, we might expect notable differences in the contact metamorphic effects produced by the two types of rocks, since such effects are believed to be produced largely by gaseous and fluid emanations from the cooling igneous masses. Field observations in Maine fail to show that contact metamorphic effects, due to the intrusions of pegmatite, are notably greater than those produced by the granites. The effects produced by both are usually slight and in many instances almost nil. Masses both of pegmatite and granite frequently cut across the foliation of schists without any distortion of the latter, the contacts being of knife-edge sharpness. In other instances pegmatite has produced some softening of the bordering rock. Such effects are confined however to the immediate vicinity of the pegmatite, usually to a zone a few inches in width, and are the exception rather than the rule, most pegmatite contacts being exceedingly sharp and free from all evidence of softening. Absorption (except in a few doubtful instances) appears to be wholly absent, the contacts, even in the cases

where softening is shown, being sharp, and the pegmatite next the contact showing no difference in composition from that at some distance away. Where schist fragments are inclosed in the pegmatite their sharp outlines are preserved.

If the physical conditions of the pegmatite and granite magmas were notably different at the time of their intrusion, it would be natural to expect some differences in the forms assumed by the granite and pegmatite masses. While in many cases the forms assumed by the two types of rocks are similar there is in general a tendency for the smaller pegmatite intrusions in the foliated rocks to assume the form of a succession of lenses while granite intrusions of similar size tend to be more nearly parallel-walled. This contrast is particularly noticeable in the Boothbay Harbor region and near Rumford Falls and is probably expressive of slightly greater rigidity in the granite than in the pegmatite magma and also of greater softening of the inclosing schist by the pegmatite than by the granite magmas. The great size of certain pegmatite masses, such as Streaked Mountain in Hebron, is on the other hand suggestive of physical conditions in some pegmatite magmas not widely different from those obtaining in normal granite magmas. The crest of Streaked Mountain was examined for over half a mile of its length, and the width of outcrop examined across the trend of the ridge was also about half a mile. The whole area traversed and the remainder of the mountain as far as it could be seen was underlain almost exclusively by coarse pegmatite, the mountain being a "boss" of this material. The pegmatite is of the usual granitic type and exhibits no more than the usual amount of variation in texture and composition from point to point. It is difficult to conceive of a mass of this size and general uniformity crystallizing under anything like vein conditions. With very high gaseous content and correspondingly high mobility it would be natural to expect more differentiation both in texture and composition. It seems probable that the specific gravity and the viscosity of such a pegmatite magma was not so much below that of a granite mass intruded under similar conditions as has been commonly supposed.

Fragments of the wall-rock are very frequently inclosed by the border portions of the granite masses of Maine. The phenomenon

is much less common in the case of the pegmatites, but was nevertheless observed at several localities. On the highest portion of Streaked Mountain a number of patches of schist a few square yards in area were seen apparently entirely inclosed by pegmatite. Small schist fragments are also inclosed by pegmatite in the Boothbay Harbor region. Dr. W. H. Emmons of the U.S. Geological Survey, who visited Mt. Mica a year later than the writer, when the excavation had proceeded farther, observed schist fragments in the pegmatite there a few feet below the schist hanging wall. These appeared to have been wholly inclosed by pegmatite, and the schistosity of the fragments made large angles with the schistosity of the walls from which they were evidently dislodged. The pegmatite shows no bending of the minerals or other changes in character near the fragments. In the instances cited the schist fragments appear to have been caught up while the pegmatite mass was still partly or wholly fluid, and *the specific gravity of the magma was sufficient, at least in the Mt. Mica example, to float the fragments.*

*Temperatures of pegmatite crystallization.*—Some evidence in regard to the temperatures of the pegmatites at the time they crystallized has been obtained from studies of quartz by Wright and Larsen,[1] a number of the specimens being collected by the writer from the pegmatites of Maine and other parts of New England.

Studies of these writers and of earlier observers have shown that at about 575° C., quartz undergoes a sudden change from one form of crystal symmetry to another. Wright and Larsen have defined the criteria which may be applied to distinguish the quartz which crystallized below 575° and that which crystallized above that temperature and has undergone reversal in the solid state upon cooling.

No granites of Maine were tested by these experimenters, but thirteen specimens of granite gneisses and quartz porphyries from other regions show as a rule the characters of high-temperature quartz, thus placing their final crystallization above 575° C.

Quartz from a dike of fine-grained pegmatite from one to four feet wide, which intrudes biotite granite near Rumford Falls, is of the high-temperature variety. This dike is typical of many of the

[1] F. E. Wright and E. S. Larsen, "Quartz as a Geologic Thermometer," *Amer. Jour. Sci.*, XXVIII (June, 1909), 423–47.

finer-grained pegmatite bodies of the state. Tests of the quartz from graphic granite in the quarry at Topsham, Maine, and a similar graphic granite collected by the writer from Portland, Conn., also showed high-temperature characteristics. Similar results were obtained with graphic granite from the Urals in Russia.

In contrast to the high temperature of formation indicated by these quartzes, tests upon specimens of rose quartz from the Maine pegmatites and from typical granite pegmatite at Bedford, N.Y.,[1] indicated crystallization at temperatures below 575°. Similar low-temperature characteristics were also exhibited by a sample from a large mass of white quartz from Topsham, Maine. This graded into quartz of graphic granite which when tested showed high-temperature characters. Quartz from a cluster of well-defined crystals occurring in a miarolitic cavity in pegmatite in Topsham showed low-temperature characteristics. This quartz group interlocked at its base with the feldspar of the wall of the pocket and plainly crystallized with the rest of the pegmatite mass. Quartz associated with lepidolite and albite in the gem-bearing portion of pegmatite from Poland, Maine, showed low-temperature characteristics. A pyramid-tipped prism of quartz from Topsham, projecting into a feldspar crystal in the midst of coarse pegmatite and plainly a contemporaneous crystallization, showed low-temperature characteristics. Crystals of smoky quartz from Poland, developed on the walls of pockets, showed low-temperature characteristics.

The results of these tests are consistent among themselves and in accord with the order of crystallization of various portions of the pegmatite established by field evidence. While it is unsafe to draw sweeping conclusions from a rather small number of tests, these are nevertheless highly suggestive, and render it very probable that while many of the finer-grained pegmatite masses crystallized above 575° C., certain portions of the coarser pegmatites crystallized at lower temperatures. In these coarser pegmatites the graphic intergrowths of quartz and feldspar crystallized above 575° C., while the coarser and more siliceous portions characterized by cavities, and probably richer in gaseous or fluid constituents, crystallized below 575°. Since

[1] Edson S. Bastin, "Feldspar and Quartz Deposits of Southeastern New York," *Bull. U.S. Geol. Survey No. 315*, 395–98.

portions showing high- and low-temperature characteristics are frequently intimately associated in the same pegmatite mass, we have here furnished a key to the general temperature of solidification of many of these bodies, namely in the neighborhood of 560–80° C.

*Eutectics in pegmatites.*—Largely as a result of the extensive studies of Vogt[1] many geologists[2] have been led to attribute an important rôle to eutectics in rock formation. One of the first[3] phenomena to suggest such a relation was obviously the graphic structure exhibited by many pegmatites, which closely resembled patterns formed by eutectic mixture in alloys. Vogt[4] calculated the ratio between quartz and feldspar in a number of analyses of graphic intergrowths of quartz with microcline, the latter mineral being also perthitically intergrown with various amounts of soda plagioclase. The ratios were constant enough to lead Vogt to conclude that the graphic granites represented eutectic mixtures. Slight disparities between analyses he attributed to slight variations in the compositions of the feldspars and to variations in the pressures under which the granites had crystallized. In many cases, especially in microscopic varieties, the graphic intergrowths are considered to be the end-products of crystallization.

In 1905, H. E. Johansson,[5] working mainly with Vogt's analyses, computed the molecular proportions of the quartz and feldspars present and arrived at the conclusion that these bore very simple numerical relations to each other. In graphic granites with dominant orthoclase the molecular ratio of feldspar to quartz was about 2:3. In an oligoclase graphic granite the proportion was about 1:2, and in an albite-quartz micropegmatite about 1:3.

Later Bygden[6] made a considerable number of other analyses of graphic granites with the special purpose of determining to what

[1] Vogt, *Die Silikatschmelzlosungen*, II, 117–35 (1903).

[2] See Harker, *The Natural History of Igneous Rocks*, 262–66, 270–72.

[3] See Teall, *British Petrography*, 401–2 (1888).

[4] *Op. cit.*, 120–21.

[5] H. E. Johansson, *Geologiska föreningens förhandlingar* (Stockholm, 1905), XXVII, 119.

[6] A. Bygden, "Ueber das quantitative Verhältnis zwischen Feldspar und Quartz in Schrift-Graniten," *Bulletin of the Geological Institution of the University of Upsala*, VII, 1–18 (1904–5).

extent the quartz-feldspar ratio is dependent upon the composition of the feldspar. He concluded that the ratio between quartz and feldspar bore no *regular* relationship to the composition of the feldspar. He believed that in most graphic granites definite ratios did exist between the proportions of feldspar and quartz but that these ratios were not always so simple as Vogt and Johansson had supposed.

TABLE SHOWING COMPOSITIONS OF GRAPHIC GRANITES

| No. | Locality | Feldspar* Percentage | Quartz* Percentage | Molecular Percentages of Feldspar Components | | | Reference |
|---|---|---|---|---|---|---|---|
| | | | | Orthoclase | Albite | Anorthite | |
| 1..... | Skarpö | 70.5 | 29.5 | 82.5 | 15.1 | 2.4 | Bygden No. 7 |
| 2..... | Hitterö | 66.0 | 34.0 | 77.6 | 21.6 | 0.8 | Bygden No. 8 |
| 3..... | Voie, Arendal | 74.7 | 25.3 | 73.8 | 24.0 | 2.2 | Vogt No. 1 |
| 4..... | Elfkarleö | 79.2 | 20.8 | 74.8 | 24.5 | 0.7 | Bygden No. 6 |
| 5..... | Topsham, Me. | 72.9 | 27.1 | 74.4 | 25.6 | none | Bastin |
| 6..... | Topsham, Me. | 73.7 | 26.3 | | | | |
| 7–8..... | Hitterö | 75.3 | 24.7 | 69.1 | 28.5 | 2.4 | Vogt Nos. 2 and 3 |
| 9..... | Reade | 72.7 | 27.3 | 66.1 | 28.2 | 5.7 | Vogt No. 4 |
| 10..... | Arendal | 76.5 | 23.5 | 63.9 | 33.7 | 2.4 | Vogt No. 5 |
| 11..... | Bedford, N.Y. | 76.8 | 23.2 | 61.7 | 37.0 | 1.3 | Bastin |
| A..... | Rödö | 56.0 | 39.0 | 9.6 | 85.4 | 5.0 | Bygden No. 9 (Holenquist) |
| B..... | Evje | 68.3 | 31.7 | 12.4 | 76.0 | 11.6 | Vogt No. 6 |
| C..... | Ytterby | 62.1 | 37.9 | 4.3 | 74.5 | 21.2 | Bygden No. 11 |
| D..... | Beef Island | 81.7 | 18.3 | 4.6 | 68.0 | 27.4 | Bygden No. 12 |

* Calculated from the analyses.

To supplement the small number of available trustworthy analyses the writer collected specimens of graphic granite from the Fisher feldspar quarry in Topsham, Maine, and from Kinkle's feldspar quarry in Bedford, N.Y. These were analyzed by Mr. Geo. Steiger in the laboratory of the U.S. Geological Survey. In order that the material analyzed should represent closely the true composition about 10-pound samples of the Maine occurrences were taken. These were pulverized, carefully mixed, and quartered down to convenient size for analysis. The New York specimen was a cleavage piece about $2 \times 3 \times 1$ inches in size.

The ratio of quartz to feldspar in the analyses published by Vogt and Bygden and in the author's analyses are given in the table above.

In Fig. 3 the composition of the feldspars are plotted on triangular projection. The numbers on the diagram correspond to those in the table.

From the table and diagram it is at once evident that even among those graphic granites whose feldspars are almost identical in composition (such as Nos. 2 to 6) there are quite considerable variations

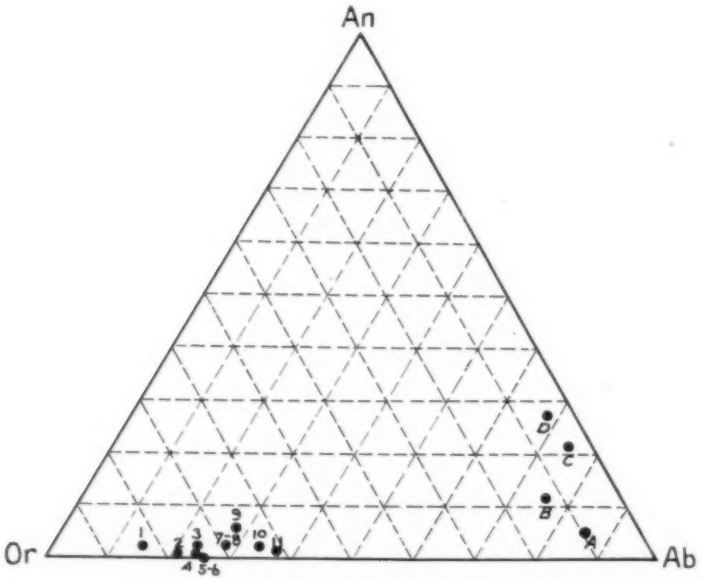



FIG. 3.—Three-component diagram showing the relationships between the molecular percentages of orthoclase, albite, and anorthite in the graphic granites tabulated above. The numbers and letters in table and diagram correspond.

in the quartz-feldspar ratio. In analyses Nos. 1, 2, 3, 7, 8, 10, and 11 (particularly in Nos. 1, 3, 7, 8, and 10) the percentage of anorthite is small and nearly constant, the only important variation being in the ratio between orthoclase and albite. No regular or consistent relationship is recognizable, however, between this ratio and the ratio between quartz and feldspar. The grouping of Nos. 1 to 11 near the lower line of the diagram signifies merely that the feldspar asso-

ciated with the orthoclase (or microcline) in graphic granites as in normal granites[1] is usually albite or oligoclase.

Both analyses and microscopic studies show that most graphic granites are mixtures of three minerals: (1) quartz, (2) orthoclase or microcline, and (3) a member of the isomorphous series of plagioclase feldspars. It should be pointed out moreover that if water or other gases were present, as it is almost certain they were, they formed additional components whose amount the analyses do not reveal but whose influence upon the proportions of the other constituents may have been great. If graphic granites crystallized from magmas of eutectic proportions, these were therefore eutectics of at least four components. *The above series of analyses, though suggesting that the proportions between the constituents of graphic granites are controlled by some laws, can hardly be regarded as proving their eutectic origin.* The theoretical value of such analyses, in elucidating the laws governing rock solutions, is impaired by the fact that they take no account of the gaseous components of the magmas.

Vogt[2] states that in many instances, especially when developed on a microscopic scale, the graphic intergrowths represent the last portions of the magma to crystallize. This fact he cites as in harmony with the conception that they represent eutectic residues. While this may be the true relation in some cases, in other cases the graphic granite was unquestionably not the last crystallization from the magma. In the Fisher feldspar quarry in Topsham, for example, where large masses of graphic granite pass gradually and irregularly into large areas of pure quartz and feldspar, the tests of Wright and Larsen (see p. 310) have shown that the quartz of the graphic intergrowths crystallized above 575° C., whereas the quartz of the large pure areas crystallized below 575°. The latter was therefore the later crystallization. The gem and cavity-bearing portions of the Maine pegmatites in almost every instance grade gradually into normal pegmatite containing abundant graphic granite. From the presence of cavities and of the rare minerals, from the general field relations, and from the fact that the quartz of the pockets and the gem-bearing portions wherever tested is of the low-temperature variety, there can

[1] See Clarke, "The Data of Geochemistry," *Bull. U.S. Geol. Survey No. 330*, 369.

[2] *Op. cit.*, 118.

be no reasonable doubt that these gem- and cavity-bearing portions rather than the adjacent graphic portions were the last parts of the pegmatite to crystallize.[1]

In considering the significance of the graphic intergrowths found in pegmatite it is necessary to consider not only the intergrowths of feldspar and quartz but also the almost equally regular intergrowths of muscovite and quartz, garnet and quartz, black tourmaline and quartz, etc. Since muscovite, tourmaline and garnet are less abundant in the pegmatites than feldspar, their intergrowths with quartz are also less abundant and usually of smaller size. Such intergrowths occur, however, scattered irregularly through practically all of the coarser pegmatite masses. If we adopt the usual conception of the eutectic as the residue of uniform composition and minimum freezing-point which is the last portion to crystallize, it is manifestly impossible to regard each of these intergrowths as representing a eutectic mixture, unless indeed several portions of the pegmatite magma are regarded as crystallizing more or less independently of the remainder of the mass.

*Mineralogical provinces.*—Most of the known pegmatites of Maine which are rich in sodium and lithium minerals, that is, the gem-bearing pegmatites, are restricted to a zone about twenty-five miles long and eight to nine miles in width extending in a northwesterly direction from Auburn in Androscoggin County to Greenwood in Oxford County. A second and much smaller area includes the Newry and Black Mountain localities in the northern part of Oxford County and differs from the larger area in that the gem minerals occur imbedded in the solid pegmatite and not in pockets. Within both areas the lithium-bearing phases form only a small proportion of the pegmatite present, most of which has the normal composition. The presence locally of certain masses of unusual composition is to be attributed either to a very minute excess of sodium and lithium

[1] In the tourmaline-bearing pegmatites of California, according to Mr. W. T. Schaller (oral communication), the zones characterized by cavities and by the presence of the gems and other rare minerals, which were almost certainly the last portions to crystallize, grade laterally without sharp break into graphic granite which borders one wall of these pegmatite masses. Occasional stringers of pegmatite bearing lithium minerals branch off from the main gem-bearing layer and cut the bordering graphic granite.

throughout the magma which gave rise to these pegmatites, over the percentages in bordering pegmatite magmas, or else to differing degrees of magmatic segregation in magmas whose average composition was similar. As already explained, quartz associated with lepidolite and clevelandite from the gem-bearing portion of one of these pegmatites showed low-temperature characters, and the unusual abundance of pockets indicates that these portions were richer than the normal in gaseous constituents, probably mainly water vapor. In general therefore the gem-bearing pegmatites were characterized by a higher percentage of sodium, lithium, and phosphorus than the normal pegmatites, and probably by more water vapor and a slightly lower temperature of crystallization.

The region characterized by pegmatites rich in fluorine minerals but not in the lithium minerals forms an area only a few miles across in the town of Stoneham and bordering parts of other towns in Oxford County and the town of Chatham, New Hampshire.

*Bearing of broad geologic relations on genesis.*—The broad geographic relationships of the granites and pegmatites are also significant of their relationship and origin. Many of the granite areas of the eastern portion of Maine are characterized by sharp boundaries, while most of the granite areas of southwestern Maine show very indefinite boundaries and are bordered by large areas of slates and schists which have been intruded by various amounts of granite-gneiss and pegmatite and by some granite and diorite. The contrast between the two types of contacts is well shown within the areas of the Penobscot Bay[1] and Rockland[2] folios. In many parts of the latter area, notably along the granite-schist contact from Bluehill village northward and from Bluehill Falls southwestward to Sedgwick, the granite preserves its normal medium grain up to the exact contact. In most places this contact is so sharp that it is possible to stand with one foot resting upon typical Ellsworth schist and the other foot resting on normal granite. Dikes and irregular intrusions of granite are not very abundant in the schists near the main granite masses, and flow-gneiss, pegmatite, and basic differentiations from the granite magma are almost entirely absent. In the Rockland quadrangle,

[1] *Geologic Atlas U.S.*, folio No. 149, U.S. Geol. Survey.

[2] *Ibid.*, folio No. 158.

on the other hand, the contact relations are wholly different, the change from pure granite to pure sediments taking place gradually through a transition zone of contact metamorphosed and injected sediments two to three miles in width. These transition zones include a great variety of rocks, slate, schist, injection gneiss, flow-gneiss, diorite, diabase, pegmatite, and granites of various textures, all associated in the most irregular manner so that it is impracticable to delineate them separately in ordinary geologic mapping. In western and southwestern Maine these transition zones are much broader than in the Rockland quadrangle and contain larger amounts of pegmatite and granite gneiss and smaller amounts of basic igneous rocks.

The contrast between the sharpness of certain granite contacts observed in the Bluehill region and the very gradual transitions observed in the Rockland quadrangle and farther southwest seem to be best explained on the hypothesis that the broad injected zones represent portions of the "roof" of granite batholiths, whereas the sharp contacts represent the sides of similar batholiths. The character of the rocks which are found in the two types of contacts lends support to this view. The more ready escape of water gas and other gases and their dissolved substances upward than laterally may explain the great abundance of pegmatite in the broad transition zones, inasmuch as the presence of such gases is believed to be the most important factor in the development of pegmatitic texture. It is a reasonable supposition that basic differentiation from the granitic magma would also be more rapid upward than laterally, and the abundance of diabase and diorite in certain of the transition zones may thus be accounted for. The hypothesis is also in accord with the low temperatures at which certain portions of the pegmatites appear to have crystallized, in comparison with the temperatures of crystallization of normal granites, and accords with the presence of numerous dikes of very fine-grained granite, some so fine as to be rhyolitic, in certain of the contact zones, and their absence about the sharper contacts.

*Summary.*—Field and laboratory studies of the Maine pegmatites indicate that all are in a broad way contemporaneous and are genetically related to the associated granites.

External conditions, though locally having some slight influence,

are not primarily responsible for the pegmatitic textures. The presence of the rarer elements seems to have had only a minor influence on the texture since in many typical pegmatites such elements appear entirely absent. Theoretical considerations and the presence of miarolitic cavities in certain pegmatites point to the gaseous constituents of the pegmatite magmas, especially water vapor, as the primary cause of their textures.

While certain facts, such as the pinch and swell phenomena observed in many pegmatite dikes in contrast with the parallel-walled character of most of the granite dikes, indicate somewhat greater mobility in the pegmatite than in the granite magmas, other facts, such as the sharpness of many of the contacts between pegmatite and schist, the absence of absorption along any of the contacts, the presence of angular schist fragments now surrounded by pegmatite, the small proportion by volume which the cavities bear to the whole pegmatite mass, the absence of notably greater contact metamorphic effects near pegmatite than near granite contacts, and the batholithic dimensions of some pegmatite bodies, all suggest that the difference in average composition between the granite pegmatites and the normal granites was perhaps not so great as has generally been supposed.

In his textbook on *Igneous Rocks* Iddings[1] in discussing the pegmatites says: "The amount of gases concentrated in such magmas was not many times that of the gases originally distributed throughout the magma from which the pegmatite was differentiated; possibly not more than ten times as much." The present writer would be inclined, in the case at least of the granite pegmatites of New England, to limit the gaseous content of these rocks still further.

The experiments of Messrs. Wright and Larsen on quartz from pegmatites from Maine and elsewhere indicate that some at least of the coarser pegmatites began to crystallize at a temperature slightly above the inversion-point of quartz (about 575° C.) and completed their crystallization somewhat below this temperature. It is probable that many of the finer-grained pegmatites crystallized wholly above 575° C.

The theory that the graphic intergrowths in pegmatites represent eutectic mixtures cannot be regarded as proven by the published

[1] Joseph P. Iddings, *Igneous Rocks* (1909), I, 276.

analyses. Certain field evidence is unfavorable to the theory that these are eutectics.

The broader field relations suggest that the large areas characterized by particular abundance of pegmatite intrusions constitute in reality the *roofs* overlying granite batholiths. Where more extensive erosion has exposed the flanks of such batholiths pegmatite masses in the bordering schists are not abundant.

# THE SOLUTION OF GOLD IN THE SURFACE ALTERATIONS OF ORE BODIES

ALBERT D. BROKAW

The leaching of gold from the outcrop of auriferous lodes has been the subject of much discussion, and many contradictory statements regarding the chemistry involved have arisen in the literature. Frequently these statements are based on experimental evidence, and the contradictions may be explained, in part at least, by a lack of uniformity in the conditions under which the experiments were carried out, and a tendency to ignore the conditions of temperature and concentration of solution that we are justified in supposing to be operative in the surface alteration of such deposits.

Clarke[1] has summarized the natural solvents for gold as reported by various observers. Their experiments, however, have been made under such a diversity of conditions that the results are not an adequate basis for comparisons, and it seemed desirable to ascertain where the emphasis should be placed in discussing this phase of the natural solution of gold.

At the suggestion of Professor W. H. Emmons, the writer undertook a series of experiments with a view of determining which of the various solvents noted are most effective in the solution of gold. By limiting the problem to alteration many substances are eliminated; only such as are known to occur in mine waters or in the gossan were studied, and the concentrations used are comparable to those shown by mine waters. The experiments were carried on at room temperature (18° to 25°), as Stokes[2] has shown that elevated temperatures have a very marked influence on the solubility of gold in ferric salt solutions.

A few of the solvents suggested by Don, Rickard, Lenher, and others were made the subject of a comparative study, the conditions of temperature and concentration being practically uniform for the

[1] Clarke, *U.S.G.S. Bull. 330*, 557.

[2] Stokes, *Econ. Geol.*, I, 650.

series. The substances studied were ferric sulphate, ferric chloride, sulphuric acid, hydrochloric acid, and manganese dioxide. These were covered by the following experiments, each in duplicate. Solution of gold is shown by loss of weight.

1. $Fe_2(SO_4)_3+H_2SO_4+Au$
   (*a*) no weighable loss.
   (*b*) " " "
2. $Fe_2(SO_4)_3+H_2SO_4+MnO_2+Au$
   (*a*) no weighable loss.
   (*b*) .00017 g. loss.[1]
3. $FeCl_3+HCl+Au$
   (*a*) no weighable loss.
   (*b*) " " "
4. $FeCl_3+HCl+MnO_2+Au$
   (*a*) .01640 g. loss. Area of plate 383 sq. mm.
   (*b*) .01502 g. " " " " 348 " "

The solutions were tenth normal[2] with respect to ferric salt and to acid. In each duplicate 50 c.c. were used. In experiments 2 and 4, 1 g. of powdered manganese dioxide was added to each duplicate. The gold was obtained from Goldschmidt Bros. and assayed 99.9 per cent pure. It was rolled to a thickness of about .002 in., and cut into pieces of about 350 sq. mm. area, and one piece, weighing about 0.15 g., was used in each duplicate. The gold was washed with alcohol and ether and dried, then each piece was carefully weighed. The experiments were carried on in tightly stoppered test-tubes which were thoroughly shaken from time to time. After two weeks the pieces of gold were removed by means of a platinum wire, and washed with water, alcohol, and ether, in turn, before weighing. In experiments 2 and 4 a small amount of manganese dioxide adhering to the plates was removed by means of a solution of ferrous sulphate acidified with sulphuric acid, after which the plates were treated as above. At the end of two weeks all but experiment 4 gave negative results when weighings were made to 0.0001 g., and the balance was ex-

[1] This duplicate was found to contain a trace of Cl which probably accounts for the loss.

[2] Normal as used in this paper refers to "equivalent normal" solutions. Tenth normal concentration was selected rather arbitrarily except for the fact that it is well within the range of concentration shown by mine waters. (See table of analyses, p. 326.)

changed for one sensitive to 0.00001 g. which was used from that time on. The whole time was 34 days. In experiment 4 it will be seen that the losses in (*a*) and (*b*) are approximately proportional to the areas of the plates.

The results of these experiments, as given above, show conclusively that, of the conditions under consideration, the most favorable for the solution of gold involve the presence of manganese dioxide and chlorides. Although it is frequently stated that gold is readily soluble in ferric sulphate solutions,[1] no loss of gold was detected after 34 days' contact with a tenth normal solution of that salt.[2]

In order to reproduce more nearly the conditions in nature experiment 5 was prepared as follows: a solution was made N/10 with respect to ferric sulphate and sulphuric acid, and N/25 with respect to sodium chloride. To 50 c.c. of solution 1 g. of powdered manganese dioxide was added and the experiment was carried on as before.[3] The loss is comparable to that found in experiment 4,

5. $Fe_2(SO_4)_3+H_2SO_4+NaCl+MnO_2+Au$
   Loss of Au .00505 g. Time 14 days.

allowing for the shorter time and the greater dilution of the chloride. The same experiment without $MnO_2$ showed no loss of gold.

After it had been shown that chlorides and manganese dioxide were necessary under these conditions, the next point to be determined was whether the free acid or the ferric chloride is the active agent in bringing about the solution. In experiment 6, 50 c.c. of N/10 HCl was used with 1 g. of powdered $MnO_2$. In experiment 7, sodium hydroxide was added to 50 c.c. of N/10 ferric chloride solution until the precipitate formed barely redissolved on shaking,[4] after which 1 g. of powdered $MnO_2$ was added.

6. $HCl+MnO_2+Au$
   Loss of Au .01369 g. Time 14 days.
7. $FeCl_3+MnO_2+Au$
   Loss of Au .00062 g. Time 14 days.

[1] E.g., *Genesis of Ore Deposits*, 478, 481, and elsewhere.

[2] This agrees with Stokes, *loc. cit.*

[3] This is essentially the experiment of Rickard, *Trans. A.I.M.E.*, XXVI, 798. From experiments 6 and 7 it appears that the ferric salt is unnecessary.

[4] Even then the solution was somewhat acid owing to the hydrolysis of the ferric chloride.

The experiments were conducted as before. The results show clearly that the free acid, rather than the ferric chloride, in the presence of manganese dioxide exercises the great solvent action, as the same amount of chlorine was present in both cases. Essentially, the most favorable conditions for the solution of gold are those in which free chlorine may be liberated.

W. J. McCaughey,[1] in studying the solubility of gold in ferric salt solutions, found that ferrous sulphate, even in very small amounts, had a marked effect in depressing the solubility of gold. Conceivably this may be a factor to be considered, and with this in view experiment 8 was performed, to determine whether ferrous sulphate, in the presence of sulphuric acid and manganese dioxide, would be quickly oxidized to the ferric salt, according to the following equation:

8. $2FeSO+2H_2SO_4+MnO_2=Fe_2(SO_4)_3+MnSO_4+2H_2O$

After acidifying 100 c.c. of 1.6 N. $FeSO_4$ solution with sulphuric acid, it was shaken vigorously with 5 g. of powdered $MnO_2$. After five minutes the solution was filtered off. No ferrous iron was detected by the ferricyanide test, showing that the iron had been completely oxidized to the ferric state. The experiments were not done in such a way that the velocity of the oxidation could be measured, but the result shows that ferrous sulphate in acid solution is quickly oxidized by manganese dioxide, hence the suppression of the solution of gold by ferrous salts may be disregarded if manganese dioxide is present. It is interesting to note in this connection that the analysis of a sample of water from the Comstock Lode,[2] showing the greatest amount of ferric iron, showed a considerable amount of manganese, but no ferrous iron; a condition exactly in accord with the right-hand side of the above equation.

McCaughey's experiments on the solubility of gold in ferric salt solutions were made with stronger solutions than are known to occur in mine waters, but his results show that gold is attacked by ferric salts in the presence of hydrochloric acid.[3] While no loss of gold

[1] McCaughey, *Jour. Am. Chem. Soc.*, XXXI, 1269.

[2] See analysis 3, p. 326. Nos. 5 and 6 illustrate the same fact.

[3] If gold is dissolved by ferric chloride the reaction might be expected to be as follows:

$$Au+3FeCl_3=AuCl_3+3FeCl_2$$

This would seem to be a reversible action, as ferrous salts are commonly used as a pre-

was noted in experiment 3 as carried out by the writer, it is possible that in a longer time some loss might be detected, as more dilute solutions act more slowly.

## SUMMARY

From the above experiments it appears:

1. That at the dilution of natural solutions of ferric salts their solvent effect on gold is probably very slight;

2. That in the presence of manganese dioxide no increased solubility is found unless chlorides are present;[1]

3. That mixtures of ferric sulphate, sulphuric acid, and sodium chloride in concentrations common in mine waters will readily dissolve gold in the presence of manganese dioxide;

4. That free hydrochloric acid in the presence of manganese dioxide has a much greater solvent effect than the same amount of chlorine in ferric chloride solution;

cipitant for gold. McCaughey, however (*op. cit.*, footnote, p. 1270), failed to detect any ferrous salt after the action had gone on for two days. It seemed probable that ferrous chloride had been formed, but was oxidized by contact with the air. Accordingly the experiment was repeated in an atmosphere of carbon dioxide, care being taken to exclude, as far as possible, all contact with the air. Several possible sources of error were not eliminated and the experiment is only of preliminary nature. The results were as follows:

| | Loss of Gold | Weight of Ferrous Iron | |
|---|---|---|---|
| | | Observed | Calculated |
| (*a*)... | 0.02904 | 0.0240 | 0.02476 |
| (*b*)... | 0.03247 | 0.0282 | 0.02769 |

This seems to establish the correctness of the equation given above. The result is not in accord with the statement of McIlhiney (*Am. Jour. Sci.*, Ser. IV, II, 293) who found that gold dissolved in ferric chloride only in presence of air. The greater dilution at which he worked may account for this.

[1] The influence of manganese compounds in chemical reactions involving oxidation is noted in many cases. E.g., Moissan (*Chim. Minerale*, V, 617) states that fuming hydrochloric acid in presence of air will dissolve gold, especially if manganous chloride is present. The catalytic action of manganese dioxide in the decomposition of potassium chlorate and hydrogen peroxide are well known. Probably manganese compounds are of considerable importance in natural oxidations, even though they may be present in very small amounts.

5. That the influence of ferrous salts in suppressing the solubility of gold is negligible if manganese dioxide is present;

6. That the solution of gold is practically limited to the oxidized zone.

In agreement with these experiments is the fact that manganiferous lodes bearing pyrite, in areas of chloride waters, are leached to greater depths than lodes that do not carry manganese.[1]

In conclusion, the writer wishes to thank Professor Emmons for his suggestions and advice in the conduct of the work, and Messrs. C. Russell and N. Sankowsky for placing at his disposal an unpublished tabulation of mine waters which they have assembled. Six complete analyses of vadose waters from their tables are appended:

| | 1* | 2† | 3‡ | 4§ | 5¶ | 6¶ |
|---|---|---|---|---|---|---|
| Cl | 12.40 | 186.40 | 127.60 | 19.00 | tr. | tr. |
| $SO_4$ | 124.80 | 161.70 | 209100.00 | 474.00 | 258.40 | 26.55 |
| $CO_3$ | ..... | 1513.44 | ..... | 20.45 | ..... | ..... |
| $NO_3$ | ..... | 1.60 | ..... | ..... | ..... | ..... |
| $PO_4$ | ..... | tr. | ..... | ..... | ..... | ..... |
| K | ..... | 198.00 | ..... | 53.40 | ..... | ..... |
| Na | ..... | 719.45 | 535.00 | 132.00 | ..... | ..... |
| Li | ..... | 2.85 | ..... | ..... | ..... | ..... |
| Ca | 46.40 | 146.41 | 1286.00 | 100.100 | 121.40 | 72.48 |
| Sr | ..... | 1.95 | ..... | ..... | ..... | ..... |
| Mg | 14.50 | 177.67 | 6590.00 | 5.88 | 13.08 | 14.90 |
| Al | ..... | 1.06 | 9760.00 | 1.37 | 1.49 | 0.37 |
| Mn | ..... | 0.57 | 885.10 | ..... | 4.72 | 4.12 |
| Ni | ..... | ..... | ..... | ..... | tr. | tr. |
| Co | ..... | ..... | ..... | ..... | tr. | tr. |
| Cu | ..... | 0.02 | 147.50 | ..... | ..... | ..... |
| Zn | 8.90 | 0.34 | ..... | ..... | 2.82 | 47.40 |
| Pb | ..... | 1.35 | ..... | ..... | ..... | ..... |
| $SiO_2$ | 18.00 | 24.42 | 616.00 | 133.40 | 2.10 | 8.00 |
| Fe++ | 6.60 | 3.50 | ..... | ..... | ..... | ..... |
| Fe+++ | | | 5025.00 | 6.33 | 4.74 | 6.30 |

* *U.S.G.S. Bull.* 330, 547.

† *Ibid.*

‡ *Bull. Univ. of Cal.*, IV, 192.

§ *Ibid.*, 189.

¶ Beck, *Nature of Ore Deposits* (Weed), II, 377. Analyses expressed in milligrams per liter. Where necessary they have been recast.

MARCH, 1910

[1] See W. H. Emmons, *Min. and Sci. Press*, December 11, 1909.

# EARTHQUAKES IN BRAZIL

J. C. BRANNER

Earthquakes are so rare in Brazil that their very rarity is a matter of interest to geologists and seismologists. In order to give an idea of the low seismicity of that country and to facilitate the collection and preservation of data in the future I have brought together in this paper all the information it has been possible to gather from a considerable acquaintance with the literature of Brazilian geology.

In January, 1909, Dr. M. A. R. Lisboa of Petropolis, a distinguished Brazilian geologist, published in the *Jornal do Commercio* of Rio de Janeiro a résumé of Brazilian earthquakes that is the most complete list thus far printed. That paper, however, is not accessible to geologists and seismologists, and I have been able to make several additions to the list.[1]

The table gives all the reported earthquakes in their chronological order, and one column shows the intensities by the Rossi-Forel scale as nearly as they can be judged from the accounts.

The papers cited include all the known publications regarding earthquakes in Brazil. There is one important article, however, bearing upon seismology in Brazil that has not been used in constructing the table, and that is a paper containing a list of eathquake shocks reported at sea off the northeast coast of Brazil by sailing masters. That article is entitled "Note sur l'existence probable d'un volcan sou-marin situé par environ 0° 20′ de latitude sud, et 22° de longitude ouest," par P. Daussy, *Comptes Rendus*, VI, 512–18 (Paris, 1838).

In his "Tremblements de Terre," *Géographie Séismologique*, M. Montessus de Ballore gives a chart of the region at p. 168.

1. *Manoel Ayres de Cazal.*—Corografia Brazilica, ou relação historico-geografica do Reino do Brazil, I, 261. Rio de Janeiro, 1817.

In his description of the province of Matto Grosso the author has this note on earthquakes: "On the 24th of September (1744) at noon, during clear weather, underground thunder was heard, and immediately the earth trembled, giving

[1] See reference No. 14 below.

several rockings that caused great alarm everywhere in Matto Grosso and Cuyabá. . . . . The earthquake that shook the Kingdom of Peru and destroyed the city

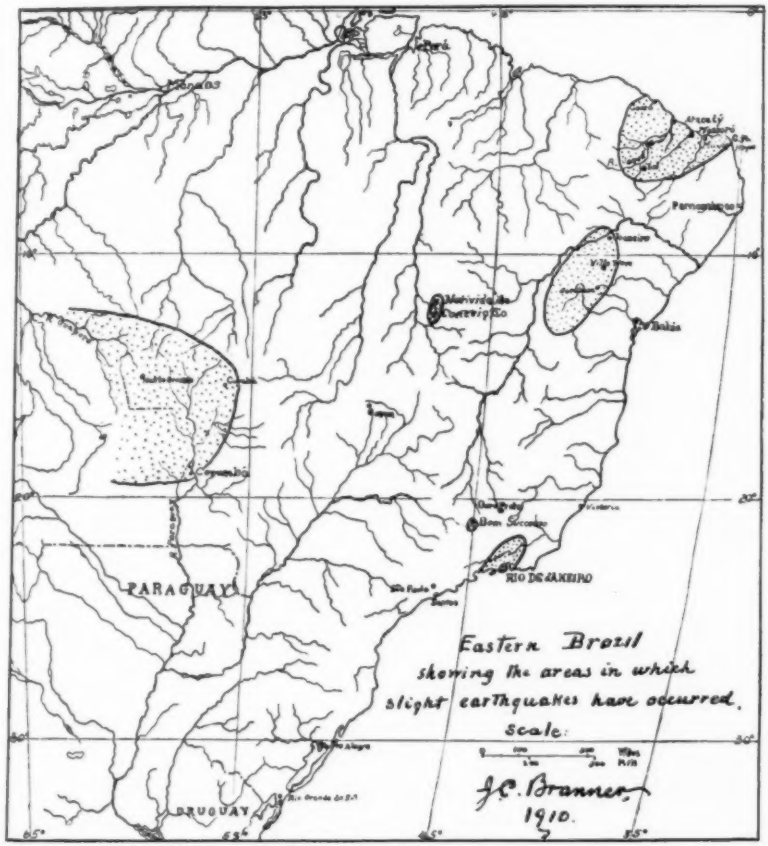
TABLE OF EARTHQUAKES REPORTED IN BRAZIL

Figures on the right refer to the authorities following the table

| Year and Date | State | Locality | Intensity (Rossi-Forel) | Authority |
|---|---|---|---|---|
| 1744, Sept. 24 | Matto Grosso | Cuyabá, etc. | VI | Cazal, 1 |
| 1746, Oct. 28 | Matto Grosso | Matto Grosso | V | Cazal, 1 |
| 1767 (9?), Aug. 1 | Espirito Santo | ..... | ..... | Capanema, 2 |
| 1807, Aug. 8 | Ceará | Jaguaribe Valley | ..... | Pompeo de Souza, 3 |
| 1810, May 31 | Ceará | Granja | ..... | Pompeo de Souza, 3 |
| 1811, Oct. 28 | Pernambuco | Recife | VI | Dom Pedro, II, 4 |
| 1812 (13?) | Rio Grande do Sul | Porto Alegre | ..... | Capanema, 2 |
| 1824 | Ceará | Jardim | VIII–IX? | Pompeo de Souza, 3 |
| 1824 | Minas Geraes | Caximbú, etc. | VI | Massena, 5 |
| 1826 | Goyaz | Natividade<br>Conceição | IV–V | Gardner, 6 |
| 1832, Sept. 18 | Matto Grosso | Principe da Beira | ..... | Fonseca, 7 |
| 1834 | Goyaz | Natividade<br>Conceição | IV–V | Gardner, 6 |
| 1846 | Ceará | Granja | ..... | Pompeo de Souza, 3 |
| 1852, Dec. 2 | Ceará | Aracatý | ..... | Capanema, 2 |
| 1852 | Ceará | Granja | ..... | Pompeo de Souza, 3 |
| 1854, Jan. 10 | Rio Grande do Norte | Touros | ..... | Capanema, 2 |
| 1855 | Ceará | Granja | ..... | Pompeo de Souza, 3 |
| 1860, Oct. 1 | Matto Grosso | ..... | ..... | Fonseca, 7 |
| 1861, June | Rio de Janeiro | Paratý, etc. | IV–V | Massena, 5 |
| 1867, Several | Minas Geraes | Jaguára | IV | Burton, 8 |
| 1876, June 26 | Matto Grosso | N. of Corumbá | IV | Fonseca, 7 |
| 1886, May 9 | Rio de Janeiro | Petropolis, Rio S. Paulo, Minas | V | Dom Pedro II, 9<br>Cruls, 10 |
| 1901, April 4<br>1901, April 5<br>1901, July 1<br>1901, Sept. 4 | Minas Geraes | Bom Successo | IV | Silveira, 4 |
| 1905, July 18 | Bahia | Bomfim to Joazeiro | IV–V | Silva, 12<br>Branner, 14 |
| 1906, Nov. | Matto Grosso | Miranda<br>Coimbra<br>Corumbá, etc. | IV–V | Lisboa, 13 |

of Lima in October, 1746, was clearly felt here; but it only frightened a few of the inhabitants."

It should be noted that Dr. Fonseca mentions an earthquake in Matto Grosso on September 24, 1749. It seems probable that there is some confusion in regard to the year. See reference 7 below.




2. *G. S. de Capanema.*—Quaes as tradições, ou vestigios geologicos que nos levam a certeza de ter havido terremotes no Brazil. Revista do Instituto Historico, XXII, 135–59, Rio de Janeiro, 1859. (Read November 24, 1854.)

Barão de Capanema wrote to the presidents of all the Brazilian provinces for information regarding earthquakes; after three years, no replies having been received, the request was renewed by the Instituto Historico e Geographico, and to these later inquiries six of the presidents replied, but apparently most of them gave negative results. The paper contains reference to some phenomena that may or may not indicate earthquakes. Capanema's list includes the two mentioned by Ayres de Cazal in Matto Grosso, and some of those given later and a little more at length by Thomaz Pompeo de Souza for Ceará. He adds one for Espirito Santo, and one for Rio Grande do Sul. The paper is occupied chiefly with a discussion of earthquakes in general.

3. *Thomaz Pompeo de Souza Brasil.*—Ensaio estatistico da provincia do Ceará, I, 51 (Ceará), 1863. Under the head of "earthquakes" the author states that a few slight shocks have been felt in the valley of the Rio Jaguaribe and at Granja, north of Fortaleza. The important footnote is here given at length:

"The following are the earthquakes of which I have been informed: On August 8, 1807, throughout the entire valley of the Jaguaribe extending northward to Fortaleza (180 kilometers), southward to Icó (300 kilometers), and eastward to Mossoró and the Serra do Martins in the province of Rio Grande do Norte.

"On May 31, 1810, at Granja, and again in the years 1846, 1852, and 1855.

"In 1824 the earth opened making a wide crack from the base of the Serra de S. Pedro to Jardim, a distance of 5 leagues, with a width of about one palm and of unknown depth.

"On December 2, 1852, at Aracatý."

4. *Dom Pedro d'Alcantara.*—Documentos relativos ao tremor de terra havido em Pernambuco em 1811. Revista do Instituto Historico e Geographico, XXIII, 401–6. Rio de Janeiro, 1860.

The date and intensity of an earthquake felt at Pernambuco October 28, 1811, are fixed by three letters written by observers in reply to inquiries made by the Emperor Dom Pedro II. One observer states that the people were filled with terror; another reports that the shock was so violent that things were nearly thrown from tables, and a fountain erected in the patio of one of the churches was overthrown. This suggests an intensity of about VI of the Rossi-Forel scale.

5. *José Franklin da Silva Massena.*—Investigaç˜es scientificas para o progresso da geologia mineira. Revista do Instituto Historico e Geographico, XLVII, 249–82. Rio de Janeiro, 1884.

This is a long article devoted to geology, but at p. 281 the following mention is made of two earthquakes:

"The earthquake of Parati in June, 1861, was quick and oscillating, and was felt in Areias and along the coast, and even at Itajubá.

"The earthquake of 1824 extended from Caximbú to Picú and was felt in the open country. Though the movements were not sufficient to kill persons or animals or to crack the earth, buildings suffered and men felt a dull, quick, rocking shock."

6. *George Gardner*, the English botanist who traveled through Goyaz in 1840, has the following in his Travels in the Interior of Brazil, etc., London (1846), 350:

"Within the last twenty years, two slight earthquakes have been felt both at Natividade and Conceição; the first occurred in the year 1826, and the other in 1834; the movement of the earth was very perceptibly felt in both places, although they were each of short duration. These were the only places in Brazil where I could learn such phenomena had been observed."

7. *João Severiano da Fonseca.*—Viagem ao redor do Brasil (1875–78), I, 198. Rio de Janeiro, 1880.

This writer, in speaking of the province of Matto Grosso, has the following upon earthquakes:

"The annals of the senate of the chambers of Cuyabá mention an earthquake on September 24, 1749, preceded by a loud noise like subterranean thunder.

"On one of the walls of the prison at fort Principe da Beira on the Guaporé I found the following inscription made there by a prisoner with the point of a style. 'On the 18th of September at two o'clock in the afternoon the earth trembled, 1832.'

"Another earthquake is registered on October 1, 1860.

"On June 26, 1876, at about half-past nine at night, while at the fazenda Cambára near the margin of the Rio Paraguay with the other members of the boundary commission, we felt a sharp shock as we lay in our hammocks and beds, and at the same time there was a rattling of the tiles of the roof as if caused by hail, the whole lasting only a few seconds."

The last-mentioned place is between the city of Corumbá and the mouth of Rio S. Lourenço.

8. *Richard F. Burton.*—The Highlands of the (*sic*) Brazil, II, 30. London, 1869.

The author, when near Jaguára in Minas Geraes, made this note in August, 1867: "Sr. Leite, an intelligent store-keeper at the Quinta, which is about half a mile from the River, assured me that the ground had lately been subject to shocks, which were most frequent about full moon."

9. *Dom Pedro d'Alcantara.*—Tremblement de terre survenu au Brésil le 9 mai 1886. Comptes Rendus, CII, 1351–52. Paris, 1886. Also in Nature, XXXIV, 1887–88. London, 1886.

This is a letter from the Emperor Dom Pedro II to M Daubrée, reporting a shock felt at Petropolis at 3:20 P.M. on the date mentioned. He notes the rattling of windows, and that the shock continued about four seconds. He reports the general area over which the shock was felt; it amounts to about 25,000 square kilometers.

10. *M. Cruls.*—Tremblement de terre au Brésil. Comptes Rendus, CII, 1383–84. Paris, 1886.

The shock described by M. Cruls, late director of the astronomical observatory at Rio de Janeiro, is the same as that reported to the French Academy by Dom Pedro II. He says it occurred at Rio de Janeiro, May 9, 1886, between 3 and 3:30 P.M., that it lasted from a few seconds to a minute, and was felt in the provinces of Rio de Janeiro, São Paulo, and Minas over an area about 250 kilometers long by 110 kilometers wide, with its longer axis lying N. 60° E.

11. *Alvaro A. da Silveira.*—Os tremores de terra em Bom Successo, Minas Geraes, Bello Horizonte, 1906. Originally published in Minas Geraes, the official organ, at Bello Horizonte, November 1, 1901.

An earthquake occurred at Bom Successo in the southern part of the state of Minas Geraes on April 4, 1901. The governor of the state appointed Sr. Alvaro A. da Silveira to collect information in regard to it. His official report along with other articles that were puulished on the same subject are brought together in a brochure of 137 pages. The following are the matters of chief interest:

The first shock that was noticed occurred at 1 P.M., April 4, 1901; it was strong enough to rattle dishes, and was accompanied by a rumbling noise.

April 5 at 5 A.M. there was a similar shock.

Subterranean sounds continued to be heard during the months of April, May, and June.

July 1 at 11 P.M. there was a strong shock, and subterranean sounds continued to be heard through July and August. During the latter half of August no sounds were heard.

September 4 at 6 P.M. a sharp shock was felt, about like that of April 4, and people left their houses. During the rest of September and during the first half of October sounds like distant thunder were occasionally heard. Between the 9th and the 15th of October there was but one rather loud rumbling; the others were all small.

He repeats that there were barely four shocks in all; that they caused no damage whatever, even to houses whose walls might easily have been thrown down.

12. *Lourenço Pereira da Silva.*—O municipio do Bomfim. Bahia, 1906, p. 37.

This is a small book of 85 pages 12° describing the natural features of the municipality of Bomfim, formerly known as Villa Nova da Rainha, in the state of Bahia. At p. 37 he says: "It must be still remembered by everyone that an earthquake shock was felt in July, 1904, throughout the zone between Bomfim and Joazeiro. It consisted of a dull rumbling followed by a slight shaking of the earth causing the rattling of dishes and bottles on the shelves of stores, while in homes ornaments and even bird cages were thrown down."

13. *Arrojado Lisboa.*—Tremores de terra no Brasil. Jornal do Commercio. Rio de Janeiro, January 23 (?), 1909.

This is part of a long article on the general subject of earthquakes, ending with a section on earthquakes in Brazil. The copy kindly sent me by Dr. Lisboa is a clipping from the daily paper in which it was printed, and does not contain the date of its publication. The article itself is dated January 22, 1909. The author mentions most of the cases in the table given herewith, and adds information gathered by himself in the state of Matto Grosso in 1908.

He concludes that the following regions in Brazil are periodically affected by earthquakes:

1. Bom Successo district in Minas Geraes.
2. State of Rio de Janiero.
3. Aracatý-Assú region in Ceará and Rio Grande de Norte.
4. The southern portion of Matto Grosso.

He mentions the seismograph in the observatory at Rio de Janeiro and urges the importance of the establishment of three additional stations under the direction of the astronomical observatory as follows: at Aracatý in Ceará or at Macáo or Mossoró in Rio Grande do Norte; at Porto Murtinho, Corumbá, or Miranda, in Matto Grosso, and a third at Bom Successo in Minas Geraes.

14. *Notes by J. C. Branner.*—While traveling through the interior of the state of Bahia in 1907 I found that a slight earthquake had been felt over a considerable area in that region in the year 1905, and the following notes were gathered in regard to it:

There is uncertainty about the year. Some of the persons with whom I talked about it stated positively that it occurred July 18, 1905. Sr. Lourenço Pereira da Silva, quoted above, says it was in 1906, but he does not mention the day of the month.

It was felt by some people, but not by all, at and about the city of Bomfim, where window shutters and bottles on drugstore shelves rattled.

At fazenda Cambão, on the west side of the Salitre Valley, the shock occurred about 8 P.M. and was accompanied by a distant rumbling sound. A man lying in

a hammock reports that it felt as if someone were jerking the cords of his hammock. The iron stirrups of saddles hanging against a wall were rattled together.

At Moita on the fazenda Ingazeira, west side of the Salitre Valley, the shock occurred between 7 and 8 P.M. Hammocks swung, dishes and pans rattled. Similar disturbances were felt at Retiro on the upper part of Rio Ingazeira.

It was felt by many, but not by all, at the city of Morro do Chapeo. A priest lying in a hammock noted that it began to swing; in the shops the bottles on the shelves rattled against each other; a partly opened door slammed; a man leaning against the wall of a house felt it give way and thought it about to fall.

The limits of the area affected were not determined with any clearness. It was not felt at all at Alagoinhas or Aramarý, but it was not ascertained certainly whether it was noticed at Serrinha or Queimadas. It has not been possible to find out whether it was felt north and west of the Rio S. Francisco. The outlines of the area affected are shown on the accompanying map as nearly as present knowledge permits.

The other two areas shown on the map are that about Rio de Janeiro, suggested by the data furnished by Dom Pedro II (reference 9), and the one suggested by the notes of Senator Pompeo de Souza (reference 3).

The Matto Grosso area is represented as extending westward indefinitely. It is so shown because it is assumed that the slight earthquakes that have been felt in that region originate in the Andean country to the west.

The following notes of negative value are not without interest:

*A. Collie.*—Geological Observations on the Neighbourhood of Rio de Janeiro. Capt. F. W. Beechey's Narrative of a Voyage to the Pacific and Behring Strait, London, 1831, II, 159.

This writer says: "Respecting earthquakes at Rio de Janero, I could get no further information than that they are rare."

*Francis de Castelnau.*—Expédition dans les parties centrales de l'Amérique du Sud. Histoire du voyage. Paris, 1850. I, 202.

This author suggests that certain steep-sided ravines near Barbacena may be due to earthquakes, but he makes no mention of earthquakes having been reported.

In Vol. II at p. 83 he says that earthquakes are quite unknown in the central parts of Brazil.

When it is remembered that Brazil occupies an area almost as large

as that of the United States, one must regard the list here given as noteworthy, and probably impossible for any other portion of the globe.

It is quite probable that, with the natural increase of population and the increased facilities for communication, the frequency of earthquakes will appear to increase somewhat in the future, but such an increase will be apparent rather than real.

# NOTES ON THE GEOLOGY OF CARRIZO MOUNTAIN AND VICINITY, SAN DIEGO COUNTY, CAL.[1]

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U. S. Geological Survey

CONTENTS

INTRODUCTION
GEOGRAPHY
EARLIER WORK
GEOLOGY
General
Descriptive
Basal Series
Effusives
Miocene Conglomerates
Miocene Shales
Superficial Deposits
Résumé of Geologic History
Conclusion
FOSSIL LOCALITIES

## INTRODUCTION

Through the courtesy of Dr. J. C. Merriam, of the University of California, and Dr. Stephen Bowers, of Los Angeles, small collections of fossil corals and mollusks from the vicinity of Carrizo Mountain, San Diego County, Cal., were sent to Dr. T. Wayland Vaughan and Dr. Ralph Arnold,[2] of the U.S. Geological Survey, during the autumn of 1903. The material in these collections proved to be of exceptional interest to the paleontologists, and in order that a larger amount might be obtained for study and more definite information secured about the geology of the region, Dr. Bowers and the writer visited the field during the latter part of January, 1904.

[1] Published by permission of the Director, U.S. Geological Survey.

[2] A brief preliminary statement of the conclusions reached by Drs. Vaughan and Arnold after an examination of these collections appears in *Science*, N.S., XIX, No. 482 (1904), 503. At that time the fauna was regarded as lower Miocene; later conclusions are to the effect that it is upper Miocene.

A light camping equipment was secured at Imperial and the drive made to Carrizo Mountain from this point. One day was spent at the Yuha Oil Well, studying the stratigraphy and collecting, then camp was established at Coyote Well on the Jacumba Springs Road. From this point Alverson Canyon and the southern slopes of Carrizo

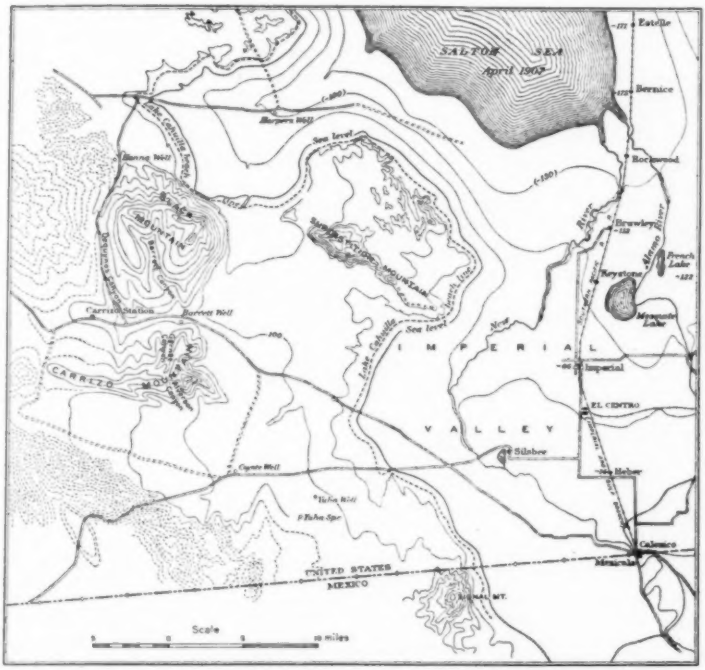


FIG. 1.—Sketch map of Carrizo Mountain and vicinity.

Mountain were accessible. Two days were utilized in work in this vicinity. Camp was then re-established about two miles below Carrizo Station, on the old stage road from Yuma to San Diego via Julian. From this point Garnet Canyon and the north slopes of Carrizo Mountain and Barrett Canyon and the south slopes of Black Mountain could be reached readily. After representative collections, amounting in all to about 1,500 pounds of material, had been made from the several fossil localities visited, the return trip to

Imperial was accomplished and the party disbanded. About ten days in all had been spent in the field.

Early Land Office maps, upon which neither roads nor relief are shown, were at that time the only official maps available, although since then, because of the rapid settlement of the Imperial Valley and the interest created in the region by the partial filling of the Salton Sink, the Geological Survey has issued a Reconnaissance Map which contains some details in the settled parts of the district but is very general in the vicinity of Carrizo and Black mountains, because these masses lie to the west of the area actually surveyed.

In 1900 and 1901 a number of oil companies were organized to prospect along the west side of the desert, between the base of the Santa Rosa Mountains and the Mexican line, and a number of engineers entered the district in the employ of these companies. Mr. I. A. Hubon and Mr. C. S. Alverson, of San Diego, were among these, and they collected data which, when assembled in a sketch map at Dr. Bowers' request, served to guide us in our field-work. From all these sources and from some sketches made by the writer the accompanying generalized map (Fig. 1) has been prepared. It does not pretend to topographic accuracy but indicates merely general geographic relations and general topographic facts without detail.

## GEOGRAPHY

Black and Carrizo mountains, known also as Fish Creek and Coyote mountains, are eastern outliers of the Peninsula Range that separates the depression occupied in part by the Gulf of California from the Pacific Ocean. They are in southeastern California near the western edge of the Colorado Desert, and from fifteen to thirty miles north of the international boundary. East of them the Colorado Desert, much of it below sea-level, extends to the Colorado River, while to the west low ridges extend to the base of the main Peninsula Range.

The two masses are separated by the valley of Carrizo Creek. This stream rises in Mexico, flows north for several miles, through a high valley in the Peninsular Mountains, then descends to the Desert level through a precipitous canyon. Nearly all of that part of its channel that lies within the desert is dry except during rare

flood periods, when its waters join those of San Felipe Creek, north of Black Mountain, and eventually reach the Salton depression. At Carrizo Station, one of the relief stations of the old Butterfield stage line, a series of springs rise, and for one or two miles below this point flowing water is found in the creek bed, except during the hottest period of summer.

The desert floor at the eastern base of the peaks is generally from 100 to 200 feet above sea-level, but on the north side of Black Mountain the sea-level contour and the old beach of Lake Cahuilla,[1] 40 feet above sea-level, swing in against the mountain base. In the past the region has been rather difficult of access, because of its remoteness from settlements and its aridity. With the colonization of the Imperial Valley since 1900 and the building of the branch railroad from Old Beach to Calexico, however, this condition has been greatly modified. Now Carrizo Station or Coyote Well may be reached by one day's drive from Imperial or El Centro, and supplies are readily secured at many points in the valley. The old roads from the desert to San Diego, the one running north of Carrizo Mountain by way of Julian and the other south of the mountain by way of Jacumba and Campo, are still much used for direct communication between the Imperial Valley and the coast, although the Campo road below Mountain Springs is rough and after storms is nearly impassable.

## EARLIER WORK

As yet there has been no detailed work done on the geological problems of the extreme southern part of California. Two important reconnaissances, however, have been carried out in that region and a number of other papers contain interesting notes.

Professor William P. Blake,[2] who accompanied one of the Pacific Railroad survey parties under Lieutenant Williamson through Southern California in 1853, wrote a comprehensive account of the

[1] *Nat. Geol. Mag.*, XVIII, No. 12, 830. In a note in this number of the *National Geographic Magazine*, Professor Blake proposes that the name Lake Cahuilla be applied to the vanished water body whose earlier existence is clearly proven by so many phenomena and whose history was first deciphered by Professor Blake himself. The name is most appropriate and the suggestion is most appropriately made by this distinguished worker.

[2] *Pacific Railroad Reports*, "Geology" (1856), V.

region which he visited and made a number of contributions of permanent value. He explored the Colorado desert, studied the effects of wind erosion in it, examined the old water-line which is so conspicuous a feature on the west side of the valley opposite Coachella and Walters, and worked out correctly both the origin of the lake whose former presence is attested to by it and the cause of this lake's disappearance.

Professor Blake made three trips along the valley of Carrizo Creek with the expedition, and brought out a few fossils which he collected from one of the flat, sandstone-capped hills on the north side of the valley. These were examined by Mr. T. A. Conrad, who pronounced the species new but probably of Miocene age.

Dr. Harold W. Fairbanks[1] visited Carrizo Mountain in the early nineties for the California State Mining Bureau, and while the exigencies of publication were such that a complete expression of his observations and conclusions was not possible, his paper is none the less very definite and satisfactory. He made hurried trips to the slopes of Black Mountain, which lies north of Carrizo Creek, and to Carrizo Mountain itself, and made collections from each locality. He described the fossils and the general geology of the district, and mentioned the corals which occur at the base of the sedimentary section.

Dr. Stephen Bowers,[2] of Los Angeles, visited the west side of the Colorado Desert in the summer of 1901, for the California State Mining Bureau. At that time there were a number of companies in the district drilling in the sedimentary rocks for oil. It was in connection with this oil excitement that Dr. Bowers' visit was made. He secured some fossils from the Carrizo and Black mountain localities which were submitted to Drs. Merriam, Vaughan, and Arnold. The interest aroused by these small collections led to the planning of the trip described here.

Other writers on the Colorado Desert have devoted themselves to general observations or to the description of particular features outside the Carrizo Mountain region. Among them may be mentioned:

[1] Fairbanks, H. W., *11th Rept., State Mineralogist of California*, 1893, 88, 90.

[2] Stephen Bowers, *Reconnaissance of the Colorado Desert Mining District*, California State Mining Bureau, 1901.

H. G. Hanks, "Mud Volcanoes and the Colorado Desert," *2d Ann. Report, State Mineralogist of California*, 1880–82, 227–40.

Chas. R. Orcutt, "The Colorado Desert," *10th Ann. Report, State Mineralogist of California*, 1890, 899–919.

Dr. Robt. E. C. Stearns, "The Fossil Freshwater Shells of the Colorado Desert, Their Distribution, Environment and Variation," *Proc. U.S. Nat. Museum*, XXIV (1902), 271–300.

## GEOLOGY

### GENERAL

Carrizo and Black mountains are islands of granitic and metamorphic rocks, which rise through encircling terranes of later sediments and volcanics. These later beds are Miocene and younger, and the unconformity which exists between them and the older rocks upon which they lie is profound. The time interval represented by this unconformity is not known because the age of the altered rocks below it is a matter of uncertainty. Fairbanks[1] expresses the opinion that they are Carboniferous or older, the opinion being based presumably upon their general resemblance to upper Paleozoic rocks in other parts of California and upon the aspect of some shells found in a float piece of siliceous limestone. Accepting this determination as the best possible in the present state of our knowledge, we must conclude that the Triassic, Jurassic, and Cretaceous systems are without depositional representatives in this region. Either the Carrizo and Black mountain areas were land masses subject to erosion during this interval or the evidence of such periods of deposition as intervened was later removed by erosional processes.

The Miocene seems to have been inaugurated by volcanic activity. On the southern slopes of both Carrizo and Black mountains are bedded tuffs, volcanic conglomerates, and less extensive masses of dark lavas of andesitic aspect. On Black Mountain there are distinct sandstones interbedded with these and directly upon them lie the Miocene coral reefs. In Alverson Canyon, which drains south from Carrizo Mountain, red vesicular lavas are succeeded by green and lavender sandstones and conglomerates, whose constituent materials are volcanic, and these in turn grade into conglomerates

[1] Fairbanks, H. W., *11th Rept., California State Mineralogist*, 1893, 88, 90.

with a diminishing proportion of volcanic pebbles. Above them are quartz conglomerates, tawny sandstones, and finally soft greenish-yellow clay shales.

An unconformity which is not especially conspicuous exists in the Miocene between the sandy shell-bearing beds, 100 feet or less in thickness, which immediately overlie the volcanics or the metamorphics, and the great mass of shales, greenish or yellowish at base, pink or pale red in general color-tone toward the top, which form the bad-land area (Fig. 2) that is especially well developed between

FIG. 2.—Lower Garnet Canyon and the adjacent bad lands cut in Miocene shales.

Black and Carrizo mountains. Finally, across the planed edges of these shale beds, a sheet of river cobbles, well rounded, has been distributed unconformably throughout the Carrizo Valley. They are probably Pleistocene, but are earlier than the silts, sands, and gravels, which represent the offshore and beach deposits of the lake which until recently has occupied the Colorado Desert. The latest erosion has left these old stream deposits stranded upon the remnants of the earlier valley floor at heights of from 100 to 200 feet above the present bed of Carrizo Creek.

### DESCRIPTIVE

*Basal series.*—The core of Carrizo Mountain (Fig. 9) is a series of metamorphic rocks in which a blue or gray crystalline limestone is

predominant. Fairbanks reports that the limestones constitute the mass of the north face of the mountain. They are likewise present in great force on the divide between Alverson and Garnet canyons, where bands of graphitic schists are associated with them, but southwest along the first-named canyon, bands of dark biotite gneiss, which presumably represent early intrusives in the limestone, are abundant. Other fresh, dark, fine-grained intrusives, which may be related to the Miocene effusives, are found in narrow dikes.

FIG. 3.—Alverson Canyon and the west slope of Carrizo Mountain.

The bedding of the marmorized limestones and the imperfect foliation in the gneisses are approximately parallel to each other and to the longer axis of Carrizo Mountain. They usually are nearly vertical, the dips in either direction being 70 or 80 degrees.

The basement of Black Mountain was observed at only a few points where the fundamental rock juts out into Barrett Canyon. Here it is a granitic plutonic, with little or no evidence of the action of metamorphic forces. Fairbanks, who examined it at a point somewhat farther east, also speaks of the rock as a granite.

*Effusives.*—West of Alverson Canyon (Fig. 3), along the north slope of Carrizo Mountain, is a conspicuous exposure of ashy, laven-

der-colored tuff, which appears to lie directly upon the metamorphic rocks. Within the canyon itself and about midway of its length, an exposure of the variegated lava, andesitic in character, has at its base a thin bed of sandstone and conglomerate, while near the mouth of the canyon the sedimentary beds rest directly upon 50 feet of tuffaceous beds, which in turn overlie the older rocks.

No effusives were observed in the Garnet Canyon section on the north slope of Carrizo Mountain, but across Carrizo Creek, in the

FIG. 4.—View down Alverson Canyon from the south slope of Carrizo Mountain.

upper part of Barrett Canyon and especially in the ridge which separates Barrett Canyon from Deguynos Canyon, just west of it, is a heavy development of the lavas and tuffaceous beds.

Here, as on the south slope of Carrizo Mountain, there is some interbedding of sandstones with the flows, which evidently issued contemporaneously with the beginning of Miocene sedimentation. These interbedded sandstones are usually bright red or pink in hue, as though partly baked by the succeeding lava stream; hence they make conspicuous exposures among the more somber lavas. The uppermost lava flow, upon whose upper surface lies the coral reef (Fig. 6) at the head of Barrett Creek, is about 200 feet thick, and overlies a sandstone bed 20 to 50 feet thick. Below this more effusives extend below the bottom of the arroyo.

In this region the accumulated effusive materials are best displayed in maximum thickness in the ridge that has been mentioned between Barrett and Deguynos canyons. They must be more than 500 feet thick here. In Alverson Canyon their mass is much less.

*Miocene conglomerates.*—In the lower part of Alverson Canyon (Fig. 4) a heavy conglomerate bed 120 to 130 feet thick overlies a series of tuffaceous strata. This bed is composed of coarse material at the base but becomes finer toward the top. It is only moderately hard and along its upper margin is an abundantly fossiliferous horizon. Splendid coral heads are imbedded in these sandstones, and more delicate forms are found at the base of the superjacent sandy shales. These corals with the molluscan remains that accompany them, all of which await detailed examination and determination, prove the age of the inclosing rocks to be upper Miocene.

On the north slope of Carrizo Mountain, about the head of the eastermost arroyos which are tributary to Garnet Canyon, another series of fragments of a well-developed basal conglomerate are encountered. They extend well up the slopes of the older metamorphic rocks which form the axis of the mountain and dip away from it toward the north or northeast at the rate of 20 or 30 degrees. Being more resistant to weathering agencies than the soft overlying shales, these have been stripped from the sandstones at many points so that the old Miocene beach (Fig. 5), its sands indurated and its teeming life preserved only in fossil form, but yet exhibiting much the aspect and much the same relations which existed at the time of its deposition, is revealed for the modern student's inspection. These basal sands are not always found where their horizon is exposed. In many places the fine clays that were spread out over the sandstones were deposited directly upon the metamorphic rocks that form the core of the mountain and must at one time have formed the bottom and shores of the Miocene sea. The simplest interpretation of this relation is to suppose that before that change of conditions was complete which substituted muddy brackish water with oyster colonies for clear sea water and marine life, the sands of the earlier beach had been swept away, so that there is unconformity, without discordance, or at least without marked discordance in dips, and without a great time interval between the deposition of the sands and

FIG. 5.—Sandstones representing the Miocene beach on the north face of Carrizo Mountain.

the deposition of the muds. The other hypothesis, namely, that these beach sands and the muds were deposited contemporaneously, because of differing local conditions, is made difficult to apply because the two physically different terranes overlie the basement rocks at very closely adjacent points, with no obvious explanation as to why such different conditions should have prevailed so near together.

The heavy sandstones occur at a number of places along the north slope of Carrizo Mountain, east of the head of Garnet Canyon. Many arroyos are incised in them, the stream channel in some cases being a mere notch but a few feet wide and a hundred or more deep. Fossils, however, have not been reported in numbers except at the head of Garnet Canyon.

At the head of Barrett Canyon, which drains south from Black Mountain, the same general relations prevail that have been described in the area a dozen miles to the south on the slopes of Carrizo Mountain. But the fragments of the basal beds of the Miocene are even more widely scattered, and the sandstones and conglomerates are not so fully developed.

About 4½ miles above the mouth and one-half mile above the forks of the Arroyo, the basal beds of the Miocene flank the older rocks and extend across the valley from the west fork to the east fork. Dips here are 20 to 40 degrees to the south, i.e., away from the mountain. The beds are not so thick as on Carrizo Mountain but are succeeded, as is the case there, by soft yellow shales.

About a mile above this point, in a little cove at the head of a small western tributary of Barrett Creek, other outcrops of basal sandstone and conglomerate, not more than 10 feet thick, occur with the underlying igneous rocks all about them. Near this outcrop is a fossil coral reef lying directly upon the lavas and isolated from all the other sedimentaries (Fig. 6). A half-mile farther north a sheet of sandstone, folded into a basin and thus somewhat protected from erosion, still exists. Doubtless many other similar fragmental exposures would be revealed by more extended search.

*Miocene shales.*—Flanking Carrizo Mountain on nearly all sides and extending on the southeast practically to Signal Mountain, on the international boundary, are continuous exposures of the beds which overlie the basal conglomerate. They are well developed also

on the southwest slopes of Black Mountain. The middle drainage basin of Carrizo Creek is a bewildering bad-land area (Fig. 7) formed by the sharp dissection of these soft clays. For many hundreds of feet above the conglomerate, the shale beds contain only occasional strata of thin brown nodular sandstone, hence they form smooth clay hills. They are entirely destitute of vegetation because of the aridity of the region, so the area in which they are found is desolate in the extreme. Fresh outcrops of the shales are to be seen only

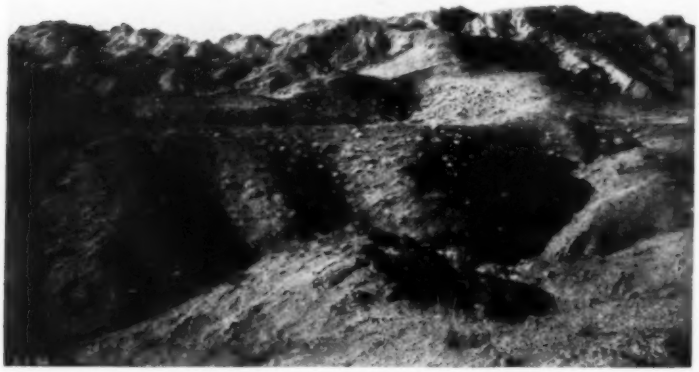

FIG. 6.—Fossil coral reef near the head of Barrett Creek.

along the flood channels where there has been recent cutting. Ordinarily each shale hill is mantled by several feet of residual material, dust much the greater part of the time, soft adhesive mud during the occasional desert rains. This mantle is the result of the weathering of the soft shales. Exposed to the air, they disintegrate completely and rapidly. This action is probably aided by the efflorescence of certain of the alkali minerals which are abundant in the shales. Wherever a thin sandstone is interstratified with them, it partially preserves them from the rapid disintegration which ordinarily affects them and so usually caps a hill which stands above the general level of the unprotected shale. Such low structural monadnocks are numerous in the neighborhood of Barrett's Well (Fig. 2).

Farther to the east and south, as in the vicinity of the Yuha Oil Well, at horizons which are presumably higher than those in the Carrizo Valley, although the conditions governing our brief reconnaissance were such that it was not possible to determine the relations with any certainty, the sandstone beds are more abundant. Many of them here weather in curious nodular forms of great variety. Such forms have been well described by Professor Blake.[1]

FIG. 7.—Erosion in the Miocene shales of the Carrizo Valley.

The Carrizo Valley is synclinal, the shales rising gently northward and southward from the axis of the valley toward the bases of Black and Carrizo mountains. Near the borders dips of 5° to 20° were measured, while in the center of the valley the beds are nearly horizontal or exhibit irregular attitudes. Faults of small displacement were noticed near the head of Garnet Canyon, others north of Carrizo Creek have been described and figured by Blake, and Fairbanks believes that the abrupt eastern face of Black Mountain overlooking the desert is a fault scarp.

In the vicinity of Yuha Oil Well more pronounced structures

[1] "Explorations and Surveys for a Railroad Route from the Mississippi River to the Pacific Ocean" (War Dept., 1857), *Geological Report* by Wm. P. Blake, p. 102.

exist, at least one district anticline with a northeast-southwest axis having been observed half a mile south of the well.

No attempt was made to measure the thickness of these beds, but the buff clays in the middle Carrizo Valley must aggregate 1,000 feet or more, and the beds with a distinctly reddish tone, which are more prominent above Carrizo Station and southeast of Carrizo Mountain, overlie them. The oil well at Yuma starts in sandy strata which appear to be stratigraphically higher than the reddish clays, and at

FIG. 8.—Old water-line marking the shore of Lake Cahuilla west of Coachella.

the time of our work in January, 1904, had penetrated over 700 feet of alternating sandstone, shale, gypsum, and shell beds.[1] The thickness of the basal conglomerate on either side of Carrizo Mountain is about 200 feet, as indicated in the generalized sections of Garnet Canyon (Fig. 10).

*Superficial deposits.*—The shale bluffs along Carrizo Creek, 50 to 100 feet high, are capped in many cases by a deposit of river cobbles three to ten feet in thickness. These cobbles are distributed over practically all of the lower shale hills within the valley whose tops are broad enough to retain the alluvium. Dissection has been so

[1] This well was afterward deepened to about 1,200 feet, but the full record is not available.

complete that the majority of these summits are reduced to mere points and lines. In these cases the arroyos and the slopes below the summits are often cumbered with the river wash which has slumped down as the hills have been reduced, but has not yet been removed. This material represents a variety of metamorphic and igneous rocks probably derived from the Peninsula Range and its outliers. Its deposition dates back to an earlier erosional cycle, when the present tops of the bad-land hills formed the bottom of the valley of the ancestor of Carrizo Creek.

Within Carrizo Valley proper and in the lowland south of Carrizo Mountain, there is the usual desert accumulation of washed material

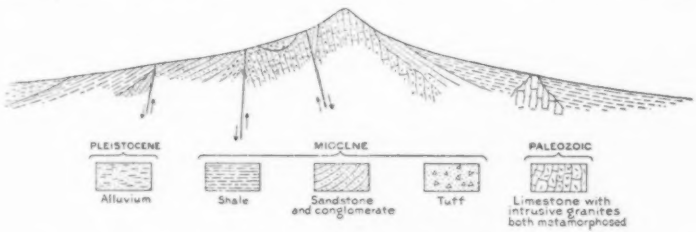


FIG. 9.—Diagrammatic section across Carrizo Mountain by way of Alverson and Garnet Canyons.

grading upward toward the mouth of each canyon into alluvial cones. West of Carrizo Station and at other favorable points in adjacent parts of the desert, there are many sand dunes, but these reach a greater development in the more open desert to the north and east.

Passing eastward beyond the valley of Carrizo Creek toward Imperial, the road at first traverses areas of well-reduced shales and sandstones, and then reaches a broad zone of beach gravels full of well-preserved shells of modern types.[1] This zone represents the beach line of the extinct lake that once occupied the Colorado Desert. The beach is not as distinct as a physical feature here as at many points farther to the north (Fig. 8) because the shore line

[1] Robt. E. C. Stearns, Ph.D. "The Fossil Freshwater Shells of the Colorado Desert, Their Distribution, Environment, and Variation," *Proc. U.S. Nat. Museum*, XXIV, 271–99.

itself was shelving and indefinite, but its general position is well marked by the molluscan remains.

Beyond and below the gravel zone is one of sand, and still farther east beyond this is the silt-covered bottom of the old lake Cahuilla. The deposits here are impalpably fine, laminated clays which, when stirred, as in a much-traveled road, become a tawny flour and when moistened are transformed into a smooth, adhesive mud.

### RÉSUMÉ OF GEOLOGIC HISTORY

The story of the development of this part of the country cannot be read with any approach to accuracy as yet for any period beyond the Miocene. The rocks which represent earlier time are marmorized limestones, schists, and gneisses as to whose age there is much doubt. The slight existing evidence points toward the Carboniferous as the period during which the limestones were deposited here. Whatever their age, their condition now indicates that their history previous to the Miocene was one involving deep burial and intense earth strain. They were upturned, intruded, and crystallized, uplifted and eroded into a mountainous topography, and at the beginning of the late Miocene formed islands in a sea teeming with life. Volcanic forces were active at this time and the flanks of the old land mass are partly buried under the effusive material which issued then, and the muds and the littoral whose fragments were supplied from volcanic sources are conspicuous at many points. But as the period advanced, vulcanism ceased and the present Carrizo and Black mountains were surrounded and perhaps for a part of the time were submerged beneath a clear sea in which the myriad forms of the life of the period swarmed. Still later in the Miocene the character of the sea changed. Instead of clear, salt water, some re-alignment of forces caused great quantities of muddy brackish water to spread about the old islands. Oysters of many forms, some of them of great size, some very tiny indeed, flourished. The heavy silts of these muddy waters accumulated to great depths as the land subsided. Finally the waters withdrew, presumably because of re-elevation, and the region was land again as it had been before, and the shells of many of the creatures which had lived in the clear and then in the muddy waters were preserved in the accumulated

sediments. As the sea withdrew, the destructive forces of weathering and the erosive forces of wind and running water became active. The clays which had accumulated were now dry and were cut away again by these forces. The process was not long continued and the plain was not completed, those clay areas which were capped by protecting sandstones remaining as monadnocks above the wide valley floor. This valley, occupied by an earlier vigorous ancestor of Carrizo Creek, was strewn with rounded river cobbles brought from the higher mountains to the west. South and east of Carrizo Mountain large areas seem to have been reduced at this period well toward the condition of a peneplain. This plain lies perhaps two hundred feet above the later Pleistocene lake-level with which it seems to have no connection. It is regarded as an earlier independent feature, perhaps Pliocene in age.

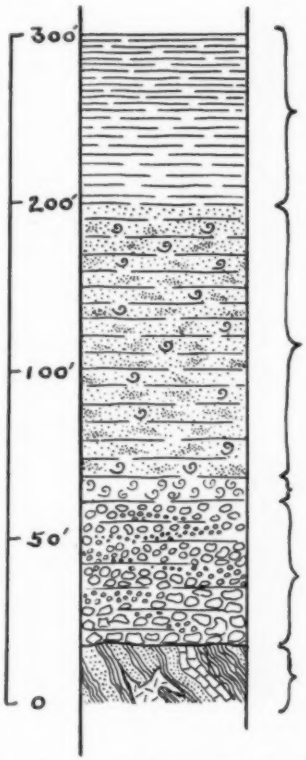


FIG. 10.—Columnar section of rocks exposed in Garnet Canyon.

After the formation of this partially planed surface, over the soft rocks of Carrizo Valley, some change either in the relations of land and sea, or of climatic conditions, enabled the streams to dissect it again. The result of this dissection, which may well have been contemporaneous with the last occupancy of the Colorado Desert by the Gulf of California, is seen in the Carrizo Creek bad lands of today.

The last important element in the development of the geography of this part of the desert was the formation and the disappearance of the desert lake. So late is it, that the calcium carbonate incrustations which it left on its western shore (Fig. 8) show but little

effect of erosive or solvent action since the waters left them, and the sandy beach, molded by the waves of the lake upon the alluvial fans which formed a large part of its shores, is still well enough preserved to be readily traced. Only the most modern gullies have cut it away. At one point a low sea cliff notched by the waves in steep alluvial-fan material still stands, as perfectly preserved as though the waters had just withdrawn.

## CONCLUSION

In conclusion it is to be said that but the barest outlines of the history of this fascinating region are yet known. Its rocks contain a rich upper Miocene fauna, probably in large part new, and its exposures and structures are so clear that its geology will be an open book to the fortunate student to whom falls the pleasant task of deciphering it in detail.

## FOSSIL LOCALITIES[1]

Shells are very abundant in the vicinity of Yuha Oil Well, but the variety is not as great here as at other localities where collections were made. A few hundred yards west of the well is an outcrop of an oyster bed which makes a conspicuous shell mound and other similar outcrops exist in the vicinity.

The horizon is the highest at which collections were made. It is probably a few thousand feet above the Carrizo and Black mountain horizons. Collections Nos. 160 and 161 were made near Yuha Well, and No. 162 was made about one and one-half miles southeast, but the horizons are not believed to be far apart.

Collection No. 165 is from a point about two miles east of the base of Carrizo Mountain. Shells are abundant here but species are limited, as is true of the vicinity of Yuha Well. These shells are probably stratigraphically lower than collections Nos. 160–62 but are higher than the others except possibly No. 168.

Collection No. 168 was made on the county road, near Barrett's Oil Well. The locality is nearly midway between Carrizo and Black mountains and must be from substantially the same horizon as Blake's original collection. It is also near the horizon of No. 165, but may be slightly lower.

No. 163 is from a small arroyo just east of Alverson Canyon, on the south side of Carrizo Mountain. The shells were taken from the yellow clays which immediately overlie the basal conglomerate. These clays contain a rich fauna which is not by any means fully represented in the collection. Stratigraphically these beds belong above the three collections yet to be mentioned. The length of the time interval between the two horizons depends upon the extent of the

[1] These descriptive notes are introduced for the use of the paleontologists who may eventually study the collections now in the U.S. National Museum.

unconformity between the conglomerates and the clays. It is probable that this interval is slight, but there are no data at hand for estimating it.

Nos. 164 and 166 are from Alverson Canyon and the head of Garnet Canyon on the south and north slopes respectively of Carrizo Mountain. The horizons are identical, being in each case the sandstones which form the upper part of the arenaceous series at the base of the Miocene. These are the most conspicuous fossil localities in the region. The shells or their casts have weathered out and strew the slopes in great profusion. Corals, echinoids, ostrea, pectens, strombus, and malea are everywhere. The matrix, however, is coarse, and only large and robust types are well preserved. The locality has been noted by prospectors generally, because the occurrences are so conspicuous.

No. 167. This collection consists of corals almost entirely. The fossil reef is near the head of Barrett Canyon and lies directly upon the igneous rocks which served as a basement for Miocene sedimentation at this point Whatever later beds may have originally covered it have been stripped away, so that the old reef is now isolated. There can be little doubt, however, that its position is at the base of the Miocene series and substantially equivalent to that of Nos. 164 and 166.

# AMPHIBIAN FOOTPRINTS FROM THE MISSISSIPPIAN OF VIRGINIA

E. B. BRANSON
Oberlin College

In the summer of 1908 a geological field party from Oberlin College collected a series of amphibian footprints from the Mississippian of Giles County, Virginia. The horizon of the prints was near the bottom of the Hinton formation, but as the line of demarkation between the Hinton and the underlying Bluefield formation is not sharply drawn it was impossible to determine the exact distance above that contact. The Bluefield in this region is about 1,300 feet thick according to Campbell, and the Hinton about the same thickness. The horizon of the tracks is about 1,300 feet above the Greenbrier limestone which lies just below the Bluefield, and 1,300 or 1,400 feet below the equivalent of the Pottsville. According to Stevenson the Bluefield and Hinton are to be correlated with the upper part of the Mauch Chunk of Pennsylvania, and it was from the Mauch Chunk of Pennsylvania 700 feet below the Pottsville conglomerate that *Sauropus primevus* Lea was collected.

The Hinton shales, like the Mauch Chunk, seem to have been subaerial in origin and are made up for the most part of variegated shales interbedded with thin layers of argillaceous, fine-grained sandstone. The footprints occur in fine-grained sandstone, and remains of land plants are not uncommon in the same beds. No marine fossils were noted by the writer in his examination of the Hinton excepting in one horizon, and that probably represented a brief transgression of the sea over delta flats. The fossils were rare and belong to only four or five species.

Twenty-two footprints made by one animal walking in a straight course were collected in a slab. They give the impression of having been made by a bipedal animal for part of the distance, but after the fourth print of the right foot impressions of the forefeet appear. The distance from tip of toe to tip of toe in the first prints is about

21 cm., but with the appearance of the prints of the forefeet the distance apart is 165 mm., 40 mm., 85 mm., 70 mm., 80 mm., 40 mm., 150 mm., and then back to 20 and 21 cm., with no more prints of the forefeet. Where only the prints of the hindfeet appear the impressions are deeper.

The hindfeet were 60 mm. in length, and 20 to 25 mm. in breadth. They had five digits, the middle digit being the longest and the two inside of it being only slightly shorter and lying close together. Their outer ends were slender and flexible and usually curved inward toward the middle toe. The two outer digits formed wide angles with the middle one and were shorter than the inner ones. The second toe was webbed to within 8 mm. of the tip, the third toe to within 23 mm. of the tip. The impression of the web is well preserved in only one impression of the hindfoot. The heel was narrow, 10 to 12 mm. in length, and not well enough distinguished in the prints to determine its exact shape.

FIG. 1.—*Dromopus aduncus* ½ natural size.

The forefeet were 45 mm. in length and had four digits. The three inner digits were subequal in length, the two inner being more flexible and incurved near the ends. The outer digit is two-thirds as long as the second. The webbing extends about half the length of the digits. The heel impression is broader than that of the hindfoot.

The distance between the inner parts of the impressions of the right

and left feet is 35 mm. and between the outer parts 90 mm. No impression of a tail is present.

The photograph reproduced in Fig. 1 is of that part of the slab showing only impressions of the hindfeet, but opposite the posterior impression a fragment from farther forward containing a track of the left forefoot is inserted. All of the feet have the heel impression shown rather indistinctly. The photograph shows the impressions of the hindfeet just behind the place where impressions of the forefeet appear.

It hardly seems worth while to attempt to classify the specimen under discussion but such an attempt may lead to a better understanding of its relationships. Using Matthew's classification it should be referred to the genus *Dromopus*, and the specific name *aduncus* is suggested, referring to the inward bending of the outer ends of the inner toes.

Amphibian footprints have been recorded from the Mississippian of America as follows:

*Paleosauropus primevus* Lea from the Mauch Chunk near Pottsville, Pennsylvania, about 700 feet from the top of the formation (*Proceedings of the American Philosophical Society*, IV [1849], 91–94, one figure).

Three unnamed varieties from about 2,200 feet from the top of the Mauch Chunk of Pennsylvania (Rogers, *Geology of Pennsylvania*, Part II [1856], 831).

*Hylopus hardingi* Dawson and *Hylopus logani* Dawson from the Subcarboniferous of Nova Scotia (*Transactions of the Royal Society of Canada*, XII, sec. iv [1894], 78).

One form from "not far from the horizon of Sauropus primaevus" in Pennsylvania (J. Barrell, *Bulletin of the Geological Society of America*, XVIII [1907], 460).

# ROCK GLACIERS IN ALASKA[1]

STEPHEN R. CAPPS, JR.

It is a generally admitted fact among observers of present-day geologic processes in high latitudes, but one upon which too little emphasis has been placed, that processes of weathering and removal of rock waste in sub-arctic regions are different from the controlling processes of degradation in more temperate regions. Among the better-known special agents of erosion active at high altitudes in temperate regions as well as in lower altitudes in sub-arctic regions, is the action of glacial ice. Of the processes not so well understood or appreciated is that of the flow of soils, or "solifluction," described for Bear Island of the North Atlantic Ocean by J. G. Andersson.[2] Mr. Andersson considers "solifluction" to be an important agent in the peneplanation of areas in high latitudes, and the process is without question a most important one in many parts of Alaska. Other processes which, according to Daly,[3] may be effective in producing an accordance of summits in mountainous regions, accordances which are generally referred to as indicating dissected peneplains, are frost action, glaciation, and wind erosion, all of which are relatively more effective above the vegetation line than below it. The accordance of summits, it is suggested, is produced by the selective action of these agents in attacking most vigorously the higher peaks. Even the ordinary processes of stream erosion are different from those of temperate climates, for the streams are frozen for about seven months a year, and during the open months their action upon the detritus is greatly influenced by the permanently frozen character of the soil, and by ground-ice.

The special agents of degradation with which I wish to deal at

[1] Published by permission of the Director of the U.S. Geological Survey.

[2] J. G. Andersson, "Solifluction, a Component of Subaerial Denudation," *Jour. Geol.*, XIV (1906), 91–112.

[3] Reginald A. Daly, "Summit Levels among Alpine Mountains," *Jour. Geol.*, XIII, No. 2 (1905), 105.

present, however, I have called *rock glaciers*. These rock glaciers occur in unusual numbers and attain exceptionally perfect development on the Nizina Special Quadrangle, where I had an opportunity to study them in the summer of 1909 while working on the geology of the region in a U.S. Geological Survey party in charge of Mr. F. H. Moffitt. The center of the area lies at longitude 143° 40′ W., latitude 61° 20′ N. On the sheet there are more than 30 of these rock glaciers and the valleys which they occupy are in every case cirques excavated at the time of the maximum glaciation of these mountains. The valleys are still on the very border line of glacial conditions, and in fact many of them still have small glaciers at their heads. The great Kennicott Glacier, in the main Kennicott Valley, occupies the bottom of the valley into which many of the rock glaciers discharge. Fig. 1 is a topographic map of a portion of the area.

In material the rock glaciers are composed of angular talus, such as goes to make up the ordinary talus slope, the kind of rock being that of the cirque walls above—porphyry, limestone, greenstone, or shale. In most cases the fragmented rock extends all the way to the head of the cirque, with no ice visible and with little or no snow on the surface. In several instances, however, the rock glaciers grade into true glaciers at their upper ends, without perceptible break. There is, therefore, a complete gradation between the two.

They vary greatly in size, but are usually many times longer than wide, occupying, as they do, the bottoms of cirque-like valleys. Some have wide, fan-shaped heads, and narrow down to a tongue below. Others are narrow above, and deploy into spatulate lobes below (Fig. 1, No. 1). Still others are formed by the junction in a valley of rock glaciers from two or more tributary valleys (Fig. 1, No. 5), but the greater number are narrow bodies of nearly uniform width, from one-tenth to one-fourth of a mile wide and from one-half to two and one-half miles long. The surface slopes vary in different cases from 9° to 18° for the whole course of the rock glacier. As topographic features they are well brought out on Mr. Witherspoon's topographic map of the area, a portion of which is shown in Fig. 1. The individual rock fragments are for the most part small, but attain, in exceptional cases, a diameter of several feet. Six inches would perhaps be about the average diameter in those rock glaciers which are com-

FIG. 1.—Topographic map of about 33 square miles of the Nizina Special Map. Eleven rock glaciers occur within this area. The numbers refer to descriptions in the text. Topography by D. C. Witherspoon.

posed largely of the porphyry, while in the greenstones and limestones the average size of the fragments is larger, and in the shales smaller than this.

The rock glaciers in form and position resemble true glaciers in noticeable ways. They head in cirques and extend from these down the valley, in cross-section being highest above the valley axis and sloping down sharply on the sides. Some were seen to have distinct lateral moraine-like ridges, and all show a more or less well-marked longitudinal ridging.

The surface markings of these rock glaciers are characteristic and striking. In the upper portions there are often many parallel longitudinal ridges, with depressions a few feet deep on either side. The sides below the cirques are usually separated from the rock valley walls by a sharp trough. Toward the lower ends the longitudinal ridges often become less prominent and give place to concentric wrinkles paralleling the lower end of the rock glacier. At the lower edges, the slope often steepens to the angle of rest for the material. The whole appearance gives one a decided impression of movement, as though the material had moved forward from the cirques in somewhat the manner of a glacier, the longitudinal lines simulating moraine lines.

The marked resemblance of these forms to glaciers led to the suspicion that ice was in some way responsible for their movement. To determine whether or not this was the case a number of the rock glaciers, seven or eight in all, were dug into, and in every instance clear ice was found; not massive ice, however, but interstitial ice, filling the cavities between the angular fragments and forming, with the rock, a breccia with the ice as a matrix. The depth below the surface at which ice was found varied according to the elevation of the rock glacier and to the portion of it examined. Toward their lower ends the ice lay too deep to be found by any shallow diggings which we had time to make. Farther up, toward the cirques in which they headed, the ice could usually be found within a foot or two of the surface, if a depression was dug into. It was often easy to get a drink of water by digging at a point where the sound of running water could be heard, and in these places clear water was found running along shallow courses among the ice-filled talus.

There is a sharp distinction between these rock glaciers and true glaciers, although in some cases it may be difficult to draw the line between the two. For the formation and existence of a true glacier it is necessary to have an annual surplus of snowfall over melt, or, in other words, to have névé fields to supply ice to the glaciers. The greater number of rock glaciers, on the other hand, are found in cirques where all, or practically all, of the winter's snowfall disappears during the summer. In true glaciers, no matter how heavily moraine covered they may be, there is always a tendency to crevass where the ice rounds a bend or passes over an inequality of the bed, and pits and irregularities of the surface are common at the lower ends where the underlying ice melts out and allows the moraines to cave in. In the rock glaciers no certain crevasses or cave-in pits were seen, and these are not to be expected if the rock glaciers are composed, as they seem to be, of talus with ice only in the interstices, for the talus itself is self-supporting without the ice, and the melting of the ice would have little effect on the surface appearance of the flow. This of course is true only of those rock glaciers which show no glacial ice at their upper ends. Of those which head in true glaciers (Fig. 1, No. 3) the upper ends would be profoundly altered if the ice should disappear, but the lower ends would probably present about the same appearance as they do now. The rock glaciers also differ from true glaciers in that, although they may advance spasmodically, or at varying rates, they never retreat, for their form remains intact even if the ice melts out and movement ceases.

The conditions necessary for the formation of one of these rock glaciers are considered to be as follows:

With the wane of the last great epoch of glaciation, the ice in many small valleys which contained glaciers was retreating, and as its area contracted in the cirques, the head walls and sides, steepened by glacial undercutting and by *Bergschrund* sapping, were exposed to the rapid weathering characteristic of bare rock surfaces in the high altitudes of this region. In the more favorably situated of these cirques the rock waste streamed down the valley sides and heads upon the glacier below and was gradually carried down by the ice and ultimately concentrated at its lower edge. Here, in the usual order of events, it would have been piled up as terminal moraine, but differ-

ing in character from the common forms of terminal moraine material in its angular, talus-like appearance and the absence of finer muds and rock flour which form such a large part of the moraines of active glaciers. Here the small, fast-dying glaciers were eroding but little, and were almost overwhelmed by the débris supplied them from above. Into the detritus at the lower edge of the glacier the waters from the melting ice and snow and from rains sank and froze, and gradually filled the interstices with ice up to a point below the surface where melting equaled the freezing. In these ice-cemented masses an incipient glacial movement was started by the well-known process of melting and refreezing of the waters, with their consequent expansion. As the climate became still milder, in many of the cirques the winter's snows all melted away during the summer, so that conditions for ordinary glacial activity no longer existed, but the bodies of talus which reached the cirque floor became filled with interstitial ice, and the movement of the mass in a glacier-like way has continued, although no doubt all true glacial ice has disappeared from many of these rock glaciers. It is certain that much snow is still carried down onto the surface of the rock glaciers in slides of ice and rock, and considerable quantities of it may be covered by débris and incorporated into the rock glaciers, but this snow probably forms only a small part of the total mass of the flow.

The above succession of events seems to be well established in this region, for there are now all stages varying from apparently active glaciers with short rock glaciers below, to rock glaciers in which no glacier ice is seen, in valleys where all snows disappear during the summer, yet in these the slow movement seems still to be in operation, the rate of movement in each rock glacier controlled by the supply of talus from above and by the shape and grade of the floor over which it moves. The rock glaciers are, therefore, the true successors of real glaciers.

The particularly perfect development of these features in the area of the Nizina Special Map is due to the rugged character of the mountains, with cirques having steep heads and sides; to the exceptionally favorable conditions for rapid rock weathering and talus accumulation; and to climatic conditions peculiar to areas on the border line of glacial activity.

FIG. 2.—Rock glacier on McCarthy Creek (Fig. 1, No. 1). Especial attention is called to the absence of perennial snows at its head; to the longitudinal direction of the surface linings in the upper portion, and to their concentric arrangement in the broad lower portion. Photo by F. H. Moffitt.

The rock glacier which was studied in most detail lies on the west side of McCarthy Creek, east of Kennicott (Fig. 1, No. 1). Although neither so long nor so large in area as others within the limits of the Nizina Special Map, it presents in a typical way many of the notable characteristics of all of the flows (Fig. 2). This rock glacier heads in a glacial cirque in a mountain composed largely of porphyry but

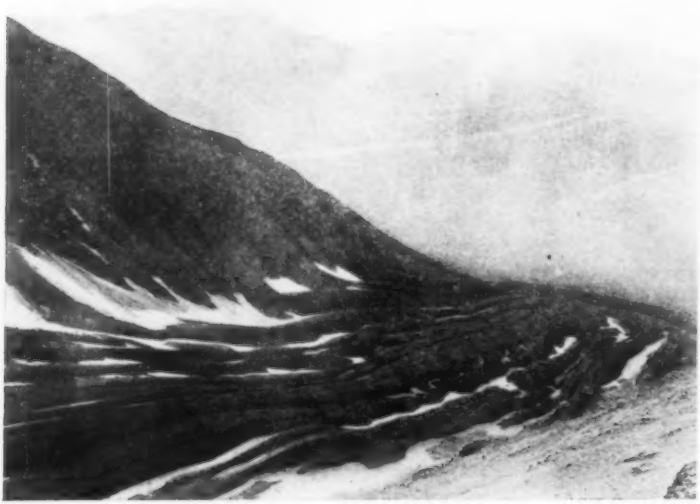

FIG. 3.—The upper portion of a rock glacier (Fig. 1, No. 2), showing the character of the longitudinal ridges, and their relations to the talus slopes in which they head.

having many inclosed masses of black Jurassic shale, the mountains at the cirque head reaching a maximum height of 6,315 feet. The rock glacier occupies the cirque floor below an elevation of 5,250 feet. Above this talus slopes extend upward for about 200 feet, the remainder of the cirque walls being bare, ragged cliffs. The porphyry is much fractured and the formation of talus unusually rapid. The valley head lies below the elevation necessary for the maintenance of true glaciers, and the winter's snows disappear completely during the summer. On July 4, the time visited, but little snow remained.

The rock glacier heads in the talus cones which have formed at the base of the steep rock cliffs. These cones have nowhere grown to large size, the materials evidently having moved on down valley as parts of a rock glacier as fast as they were supplied from above. From the base of the more vigorous talus cones smooth, ridgelike lines extend on down the rock glacier, seeming to show that the forward

FIG. 4.—Profile of rock glacier on McCarthy Creek (Fig. 1, No. 1). The surface scope of the rock glacier conforms in a noticeable way with the glacial U-shape of the McCarthy Creek valley.

movement has been uniform and continuous. This is especially well shown for the flow on the opposite side of the ridge (Fig. 1, No. 2), in Fig. 3. The longitudinal ridges mark the surface for the upper three-fourths of the total length of the flow. The cirque basin is a hanging valley extending down to an elevation of about 4,000 feet, below which it joins the broad V-shaped valley of the McCarthy Creek. As it passes over the lip of this hanging cirque the rock glacier cascades steeply down the valley side (Fig. 4), and upon reaching the gentler slope below, being no longer confined by restricting valley

walls, it spreads out in a great lobe along the valley bottom. In this lower lobe the longitudinal surface markings disappear and give place to a set of concentric ridges or wrinkles, shown in Fig. 2, and in greater detail in Fig. 5. The origin of these wrinkles is not clear, but they strongly suggest rings of growth, and may represent the amount of annual movement of the rock glacier.

FIG. 5.—Concentric ridges on lower portion of rock glacier in McCarthy Creek valley (Fig. 1, No. 1).

At its foot the flow has pushed across the valley bottom almost to the base of the east valley wall. McCarthy Creek has been forced to the eastward, and occupies a narrow channel between the foot of the rock glacier and the rock valley wall (Fig. 6). The foot of the rock glacier is being cut into by the stream, and in places shows a face 75 to 100 feet high in which the slope is about 35 degrees, or the angle of rest for this material. The stream has been able only to keep its channel open along the foot of the rock glacier, and it seems probable that the flow is moving forward as fast as the stream can cut it back.

I have been able to find in the literature scant reference to features of this kind. In the Falkland Islands there are so-called "stone rivers," described by Thomson,[1] Andersson,[2] and others, which seem to correspond closely to those in the area here described, but which occur on much lower slopes. Andersson, in an article on "Solifluction," or soil flow, thinks that these Falkland "stone rivers," which now

FIG. 6.—Lower end of rock glacier on McCarthy Creek (Fig. 1, No. 1). The material at the edge lies at an angle of 35°. The stream has been able to keep open only a narrow channel at the base of the rock glacier.

are composed of angular blocks, were formerly filled with fine mud and that the blocks of rock, buoyed up by the mud, slowly flowed down the valleys. He conceives that the fine material has since been removed by running water. There is now no movement of these "stone rivers."

The rock glaciers do not fall under the term "solifluction," as used by Andersson, for he describes a movement of rock débris com-

[1] Thomson, *The Atlantic*, 245. [2] J. G. Andersson, *op. cit.*

posed of angular fragments mingled with a matrix of mud, which moves as a viscous fluid. The material of the rock glaciers is for the most part coarse and angular, and instead of a semi-liquid filling of mud, the interstitial openings are filled with solid ice, except in the surface portions, where there is no filling at all.

There is also an opportunity for interesting comparisons with the rock slides of the San Juan Mountains of Colorado, so well described by Cross and Howe[1] in the Silverton Folio and by Howe[2] in a recent publication. At first glance there seems to be a great similarity between the rock streams of the Colorado Mountains and the rock glaciers of the area under discussion. Both are composed of angular talus from high mountains, and show some striking similarities in appearance and in surface configuration. I am convinced, however, that the rock glaciers of the Nizina region are not formed in the way in which Mr. Howe[3] explains his rock streams, by a flow down the slopes "with a sudden violent rush that ended as quickly as it started." No opportunity has so far been had to make a series of observations extending over a considerable period of time to prove conclusively that these rock glaciers are in motion, or to determine the rate of movement. There are a number of facts, however, which seem to lead inevitably to this conclusion.

In the Silverton Folio, published in 1903, Cross and Howe state: "The larger rock streams, however, must owe their origin to glaciers; no other agencies could transport such vast quantities of rock waste so far from their sources." Later, Howe has published his opinion that the rock streams of the San Juan Mountains are really landslides, which occurred in a sudden violent rush of material. In this opinion Cross now agrees with him.

In his description of the great Elm landslide, Heim[4] has pointed out that sudden landslides may have a form remarkably similar to that which is developed by slow movement, and it is well to keep this

[1] Whitman Cross and Ernest Howe, *U.S. Geol. Sur. Folio*, No. 120, Silverton.

[2] Ernest Howe, "Landslides in the San Juan Mts., Colo.," professional paper, *U.S. Geol. Sur.*, 67, 1909.

[3] *Ibid.*, p. 54.

[4] Albert Heim, "Der Bergsturz von Elm," *Zeitschr. Deutsch. Geol. Gesell.*, 1882, 98.

fact in mind. McConnell and Brock,[1] on the other hand, in their report on the Frank landslide, fail to report any systematic ridgings like those at Elm, or in the rock streams of the San Juan Mountains.[2]

Perhaps the most indicative facts which lead us to conclude that the rock glaciers of the Nizina region are now in motion, moving in some such way as a glacier, are:

FIG. 7.—The upper end of a rock glacier, showing the cirque-like character of the valley head, and the origin of the longitudinal ridges in the talus slopes of the head walls.

1. The remarkable resemblance in position and form to present live glaciers in the immediate vicinity.

2. The direct connection and perfect gradation between present glaciers above and long rock glaciers below.

3. The presence of interstitial ice at no great depth below the surface in all of the rock glaciers which were dug into.

[1] R. G. McConnell and R. W. Brock, "Report on the Great Landslide at Frank, Alta., 1903," *Ann. Rept.*, Dept. Interior, Canada, 1903, pt. 8.

[2] Ernest Howe, *op. cit.*

4. The longitudinal ridges seen at the upper ends of many of the rock glaciers can often be followed directly to an active talus slope (Figs. 3 and 7).

5. Nowhere have the talus slopes at the heads of the cirques been able to form any considerable accumulations on the surface of the rock glaciers. This seems to be very strong evidence that the talus

FIG. 8.—A small rock glacier north of Sourdough Peak. The characteristic steep lower face of these features is well shown.

has moved on down the valley as fast as it has been supplied (Figs. 3 and 7).

6. In all of the best examples of rock glaciers there is a steep slope at the lower end where the gently sloping surface of the upper portion breaks down at the edge at an angle as steep as the talus will lie. Over this steep face the rock fragments are fresh, while the talus on the surface above this slope is usually lichen covered. This seems to show that the material is moving forward fast enough to prevent erosion of the lower end from reducing it to a low, graded slope (Fig. 8).

FIG. 9.—Rock glacier in McCarthy Creek valley (Fig. 1, No. 4). It terminates below at the mouth of the hanging valley in which it lies, this being the point at which the interstitial ice fails to make possible a slow glacier-like movement. The material from the end of the rock glacier has streamed down to form a well-developed talus cone. Photo by F. H. Moffitt.

7. In the fine example on the west side of McCarthy Creek (Fig. 1, No. 1), the creek, a swift stream of large volume, is now actively cutting into the lower end of the rock glacier, which has been in existence long enough for large spruce trees to grow upon its surface. Nevertheless, the creek has so far been unable to do more than keep a narrow channel open along the foot of the rock glacier (Fig. 6).

FIG. 10.—Rock glacier at head of White Creek. The detritus from the two sides of the rocky island flows together to form a single stream below it.

Yet there is no evidence that the rock glacier ever extended the 75 feet farther east which would have carried it to the rock bluff on the east side of the valley. It seems unusual that this mass of material, if it came down with a rush, should have failed by just the width of the creek to cross the valley, and also that the stream, which is now actively cutting into the face of this rock glacier, has been unable to do more than keep its channel open. It appears as much more probable that the slowly advancing edge of the rock glacier has been removed by the stream as rapidly as it has moved forward.

8. There is no evidence that important landslides have taken place

in this region, if these features are not landslides. None were seen below the miles of prominent, steep cliffs of the area, though ordinary talus cones are abundant.

9. One rock glacier, in a western tributary of McCarthy Creek (Fig. 1, No. 4, and Fig. 9), shows all the characteristics of a typical rock glacier at its upper end, but at the mouth of the hanging valley on which it lies, it streams down to McCarthy Creek as a very perfect talus cone. If it had come down suddenly as a landslide, no such perfect talus cone would have been formed. The presence of the talus cone indicates that the material of which it is composed was supplied slowly, thus enabling the cone to build up symmetrically. The talus cone is still being supplied with material by the rock glacier, as may be seen in the figure from the way in which the talus from above is invading the patch of alder bushes on the side of the cone.

10. Wherever two rock glaciers in adjacent cirques join below to form a single flow, the point of junction shows that the two branches have flowed together synchronously without any evidence that the flow from one branch has come down and overridden that from the other (Fig. 10).

# THE GLACIAL LAKE MISSOULA[1]

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The object of this paper is to show that in comparatively recent time an ice-dammed lake filled a large part of the drainage basin of the Clark Fork in northwestern Montana.

To prove the existence of the lake is set forth what evidence has been found in the literature of this region together with a contribution by the writer, whose observations, made at odd times during the past decade, were confined mainly to the Missoula and Bitter Root valleys.

Belief that the lake was ice-dammed was sugggested by certain of the phenomena of this area, but is based mainly on information derived from the writings of others, from which also the probable location of the dam is determinable.

The writer is indebted to Mr. F. C. Calkins, of the United States Geological Survey, for suggestions and criticism.

As long ago as 1885 Professor Chamberlin[2] noted a curious phenomenon in the Flathead lake region that he aptly describes as "a series of parallel watermarks of the nature of exceptionally slight terraces sweeping around the sides of the valley and encircling the isolated hills within it, like gigantic musical staves."

In the vicinity of Missoula similar phenomena have been observed by Professor Salisbury[3] and are noted by Douglass[4] who mentions that "in the Missoula and Bitter Root valleys on the mountain sides and along the foothills are level lines or small terraces, evidently shorelines, formed by the dashing of the waves"; and a brief reference to

[1] Published by permission of the Director of the United States Geological Survey.

[2] T. C. Chamberlin, "Administrative Report," *U. S. Geological Survey, Seventh Ann. Rept.*, 1885–86, 78.

[3] Personal communication.

[4] Earl Douglass, *The Neocene Lake Beds of Western Montana*, published by Montana University, 1899, 10, 11.

them is made by Wood[1] who records that "at Missoula . . . . around the mountains a series of beaches or beach lines extend. . . . ."

The photograph of Mount Jumbo (Fig. 1), a well-known landmark at the mouth of Hell Gate Canyon, brings out more plainly than any written statement could the striking horizontality of these parallel lines. The partly melted snow rather emphasizes them;

FIG. 1.—Hell Gate Canyon, Mount Jumbo, from near Northern Pacific dépôt, Missoula.

still when the ground is entirely bare they can be plainly seen from the city, and have been interpreted by some of the pioneer inhabitants as "old buffalo trails." At close range it is difficult to locate definitely any but the more prominent "trails," the highest of which has an elevation above Missoula of 1,000 feet or 4,200 feet above sea (this and the subsequent elevations as given were determined by aneroid).

University Mountain (Fig. 2), the opposite sentinel of the Hell Gate, exhibits on its western slopes a series of "trails" that are

[1] Herbert R. Wood, "Glaciation in Western Montana," *Science*, XX (1902), 162.

clearly seen to be a continuation of those of Jumbo. From here they may, with many interruptions, be traced to the south along the eastern slopes of the Bitter Root Valley as far as Skalkaho Creek. Again, similar horizontal lines may be seen on the valley's western slopes north of Lo-Lo Fork in situations nearly free from timber. South of Lo-Lo Fork, if they exist, they are obscured by the forest clothing the foothills of the Bitter Root range. Elsewhere, in the

FIG. 2.—University Mountain, from University Avenue, Missoula.

northern slopes of the Missoula Valley below the city of Missoula, and of the Jocko Valley near the Flathead agency, similar "trails" have been noted from a distance. Farther down along the main Clark Fork Valley the slopes are steeper and rocky, and to a great extent timbered. Here the "trails," if they exist, have apparently not as yet been seen, but certain phenomena of this region, as will appear later, may have an intimate relation to them. From unpublished observations of Mr. F. C. Calkins in this area it appears that in the valley of Vermilion Creek an extensive gravel flat trenched by the stream is found at 4,000 feet (aneroid) elevation, and that similar

but less extensive deposits are developed at about the same elevation in small canyons opening into the Clark Fork Valley between Vermilion Creek and Thompson Falls.

East of the town of Stevensville a chain of rounded hills projects westward some 5 or 6 miles into the Bitter Root Valley as a spur from its eastern wall. This spur as a whole descends gradually from an elevation of 6,500 feet to about 3,600 feet where its steeply tilted quartzites disappear beneath the horizontally bedded clays, sands, and gravels that form the valley terraces or "bench lands," which bear a

FIG. 3.—Cowell buttes, looking southeast from sec. 6, tp. 9, N.—19 W. Montana Mer., showing the horizontal "trails" marked by rows of trees and shrubs.

thin, clayey, fertile soil that as a rule is sharply defined from the underlying gravel. The two symmetrically rounded outer knobs of this spur are locally designated the Cowell buttes (Fig. 3). The westernmost or first butte attains an elevation of 4,450 feet; the second butte 4,750 feet, while the saddle between is 4,250 feet above sea. The "trails" are well developed on the north and northwest slopes of these buttes; the one at 4,200 feet elevation, above which they apparently fail, is comparatively prominent and its cross-section resembles that of a neglected road grade. The upper bank is broken down but still definable, and the "road bed" eight or ten feet wide merges gradually with the steeper slope below. The sandy soil of this "road bed" is much deeper than that of the slope above and contains numerous subangular to smooth rounded pebbles of quartzite

that in the slopes above are wanting. These pebbles range in size up to four or five inches in diameter and, together with larger masses of quartzite associated with them and possessing rounded edges, are undoubtedly waterworn. Among them no pebbles of a material differing from the quartzite bed rock of the immediate vicinity are found. This "trail" can be easily followed around the north slopes of the buttes, tracing a deep re-entrant angle as it curves around the head of the ravine leading north from the saddle. Here the pebbly deposit gives place to a more extensive one of fine, slightly yellowish, quartz sand, that in one place has been channeled by a rain gully to a depth of eight or ten feet.

Below the 4,200-foot contour the slopes exhibit a succession of parallel trails, exact counterparts apparently of those of Mount Jumbo, except that many of them are conspicuously marked by rows of trees and shrubs. One at 3,700 feet elevation is more than ordinarily prominent. It might at one place be easily mistaken for an abandoned wagon-road along which a row of trees had been set. Its cross-section is similar to that of the one at 4,200 feet, but of larger proportions, the "road bed" twelve to fifteen feet wide being likewise formed of a deeper soil than is found upon the adjacent slopes, containing waterworn pebbles and quartzite fragments.

Just below this contour the quartzite disappears beneath the incoherent sediments of the "bench lands" upon which the series of "trails" still continue to be faintly exhibited down nearly to the river's flood plain.

Douglass[1] describes these benches as beds of sand, gravel, and volcanic ash of Miocene age in part. Remnants of the "trails" are not only preserved upon open slopes of this easily eroded material, but upon the sides of the ravines that dissect it, showing that time since the "trails" were formed has been too brief for any material alteration of the topography by erosion.

On the northern slope of the first butte at about 4,100 feet elevation a large subangular bowlder of gneissoid granite rests upon the surface. It has a volume of perhaps five cubic yards. Several similar bowlders have been noted in the neighboring basin of Three-Mile

[1] Earl Douglass, "A Geological Reconnaissance in North Dakota, Montana, and Idaho, etc.," *Carnegie Mus. Annals*, V (1909), 264, 265.

Creek, and elsewhere in the eastern half of the Bitter Root Valley but in no case at a greater elevation than that recorded.

These bowlders are clearly seen to be erratics, not only from their haphazard distribution, but from the fact that their parent rock is not to be found anywhere in their vicinity nor even in the mountains that form the valley's eastern wall from Skalkaho Creek north.

A strikingly similar rock is, however, the prevailing type of the opposite Bitter Root range.[1]

South of Hamilton in front of the canyons of Lost Horse, Rock, and other creeks heading in this range, moraines extending down to 4,000 feet elevation are found.[2] It is perhaps needless to add that elsewhere the Bitter Root Valley has not been glaciated.

The foregoing phenomena as a whole seem explainable only as the records of an extinct lake or sea. The old "buffalo trails" are the existing remnants of its wave terraces. Its high level was approximately 4,200 feet above sea. At this stage the site of the present city of Missoula was 1,000 feet under water, and glaciers from the Bitter Root range south of Hamilton reached the lake, setting bowlder-laden icebergs afloat upon it. One of these bergs grounded on the prominent cape formed by the Cowell buttes.

During the lake's halt at this level its waves worked considerable fine material into the head of the small bay or cove between the buttes, the remnant of which is still to be found in the upper course of the ravine descending from the saddle. Sediments that settled from this lake are believed to be the main source of the soil referred to on p. 378, to which the agricultural value of the "bench lands" is due. The gravel flats observed by Mr. Calkins in some tributary valleys of the Clark Fork are explainable as delta deposits in a lake. The lake receded gradually, recording many brief halts and a comparatively long one at 3,700 feet.

Douglass[3] suggests "that the water cut with comparative rapidity through its barrier in geologically recent times."

[1] Waldemar Lindgren, "A Geological Reconnaissance across the Bitter Root Range and Clearwater Mountains in Montana and Idaho," *Professional Paper, U. S. Geol. Survey*, No. 27, 42–47.

[2] *Ibid.*, 51–55, and Plates I and X.

[3] Earl Douglass, *The Neocene Lake Beds of Western Montana*, published by Montana University, 1899, 11.

In order to understand the problem of the locality of the dam it is necessary to glance briefly at the topography of northwestern Montana and the adjacent panhandle of Idaho. From the map (Fig. 4) it appears that that portion of Montana west of the continental divide

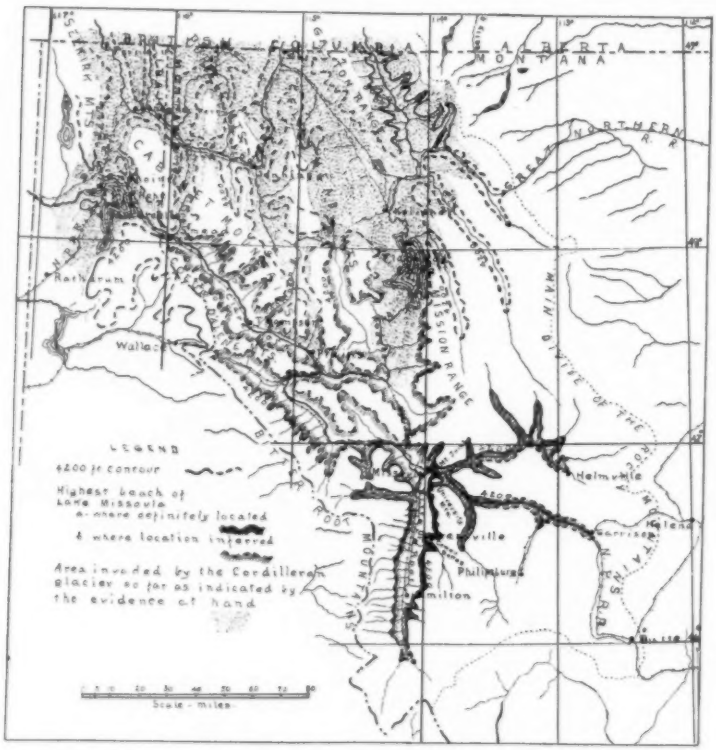


FIG. 4.—Map of northwestern Montana and adjacent portions of Idaho compiled from the U. S. General Land Office maps of Idaho and Montana, topographic sheets of the U. S. Geological Survey, etc.

is largely occupied by an irregular depression, drained by Clark Fork of the Columbia River. If this depression were filled with water to the 4,200-foot contour, the lake formed would be effectively imprisoned on the east and south by the main divide and on the southwest by the Bitter Root and Cœur d'Alene mountains, but to the northwest no

continuous barrier exists, a partial one only being afforded by the detached Cabinet, Flathead, and Galton ranges. Between the latter and the continental divide the valley of the upper Flathead River at the 49th parallel sinks slightly below the given plane, and continues, as a depression (the Rocky Mountain trench of Daly),[1] a great distance northwest into British Columbia.

Between the Galton range and Cabinet Mountains is a considerable area which, although partly occupied by the Flathead Mountains, affords two broad passes through which the water would escape to the Kootenai Valley. South of the Cabinet Mountains, the Clark Fork Valley is depressed at the Idaho-Montana boundary 2,100 feet below the 4,200 level. At this point the valley is rather constricted, its cross-section showing a width of three miles near the river level, and about seven miles at 4,200 elevation.

Of special interest to the problem at hand are three north-south depressions that join the Clark Fork and Kootenai valleys. The largest and most important of these is the Pack River or Kootenai Pass through which the Great Northern Railway crosses from Bonners Ferry on the Kootenai to Lake Pend d'Oreille. It is a rather broad, deep valley whose highest point is about 150 feet above lake Pend d'Oreille and is in reality, as shown by Calkins,[2] a part of the Purcell trench, a depression extending northward 200 miles beyond the 49th parallel.

The two smaller trenches cross the Cabinet Mountains east of this one, the Bull Lake trench[3] affording an easy pass with only 700 feet climb, between Smead on the Clark Fork and Troy on the Kootenai, and, farther east, a depression crossing the same mountains between Plains and Jennings. From the foregoing it appears that at the present time a barrier of sufficient height across the depressions just described would restrain a lake in the drainage basin of the Clark Fork, whose waves would terrace the 4,200-foot contour.

This would also be the case in Pleistocene time if the physiography

[1] Reginald A. Daly, *The Nomenclature of the North American Cordillera between the 47th and 53d Parallels of Latitude, Geog. Jour.*, XXVII, No. 6 (1906), 596–98.

[2] F. C. Calkins, "A Geological Reconnaissance in Northern Idaho, and Northwestern Montana, *Bull. U. S. Geol. Survey*, No. 384 (1909), 16.

[3] *Ibid.*, 15.

of this region was then the same as now. This is for the purposes of argument assumed to be essentially true, such crustal warping and modification of the surface by erosion as have occurred during or since that time being, as indicated by the evidence at hand, insufficient to have seriously altered the topography of this region.

The evidence of icebergs, together with the apparent recency of the lake and the variable height of its surface, connect this lake with the glacial period, and readily lend themselves to the suggestion that its dam was of ice.

Bailey Willis has suggested that this was a Pleistocene lake dammed by a glacier.[1] Many years ago Professor Chamberlin conceived the idea of a glacial dam and furthermore tentatively suggested that its location was in the Pend d'Oreille region with outflow by way of Spokane.[2]

While there has been some local glaciation in the Cœur d'Alene and Cabinet mountains[3] it is evident that these small glaciers were inadequate to have themselves formed the dam, although they may have aided in its production.

That British Columbia was formerly buried under a vast accumulation of ice, generally referred to as the Cordilleran ice-cap, has been made known by the writings of Dawson and others. It appears that south-flowing portions of this ice-cap were even at the 49th parallel of great depths.[4] Its margin was markedly lobate, south-flowing tongues having occupied every large valley that crosses the International Boundary between the Cascade Mountains and the continental divide. To this ice invasion the "trenches" characteristic of this region owe, in a certain measure, their form and fairly constant depth.

While the limits of these great valley glaciers which crossed the boundary west of the Idaho panhandle are fairly well known, knowledge of those east of that point is more or less fragmentary. Some

[1] Earl Douglass, *The Neocene Lake Beds of Western Montana*, published by Montana University, 1899, 11.

[2] Personal communication.

[3] F. L. Ransome and F. C. Calkins, "The Geology and Ore Deposits of the Cœur d'Alene District, Idaho," *Professional Paper, U. S. Geol. Survey*, No. 62, 15, 57; and F. C. Calkins, *op. cit.*, 15.

[4] R. A. Daly, *Can. Geol. Survey, Summary Report*, 1903, 93; *ibid.*, 1904, 95.

idea of the great depth near the 49th parallel of the one that flowed south through the Rocky Mountain trench may be gained from the fact that here it overflowed eastward across the continental divide through Ahern and other passes at the head of Belly River.[1]

The eastern or upper Kootenai Valley held another great south-flowing glacier.[2] At Kalispell, about sixty-five miles south-southeast from the boundary at the point just referred to, the ice was 3,000 feet deep, or its surface nearly 6,000 feet above sea, and came from the north-northwest.[3]

This lobe, probably reinforced by that of the upper Flathead Valley, flowed southward across the Flathead lake region, reaching, as indicated by the observations of Professor Elrod,[4] to the Jocko Valley. A deep glacier flowed south through the Purcell trench, extending at least to the southern end of Lake Pend d'Oreille.[5] At the north shore of this lake, ice is shown by Calkins[6] to have been about 2,500 feet deep.

The same author has also noted the glaciation of Clark Fork Valley above Lake Pend d'Oreille in the vicinity of Bull River,[7] and his observations, with those of Wood,[8] indicate the ice to have been at least 2,000 feet deep. Bull Lake trench probably supported another deep ice-stream[9] that may have been a branch from the Purcell lobe at Bonners Ferry. There is also evidence to indicate that south-flowing ice occupied the Kootenai Valley above Libby,[10] and also the Plains-Jennings depression.[11]

[1] G. E. Culver, "Notes on a Little-known Region in Northwestern Montana," *Trans. Wis. Acad. Sci.*, VIII (1891), 204.

[2] R. A. Daly, *Can. Geol Survey, Summary Report*, 1904, 95.

[3] R. D. Salisbury, "Glacial Work in the Western Mountains in 1901," *Jour. of Geol.*, IX, 724.

[4] M. J. Elrod, "The Physiography of the Flathead Lake Region," *Bull. University of Montana*, No. 16, 202.

[5] T. C. Chamberlin, *Seventh Ann. Rept. U. S. Geol. Survey*, 1888, Plate VIII, 178, 179, and Fig. 15; *ibid.*, "Administrative Report," 1885–86, 78; and Bailey Willis, "Changes in River Courses in Washington Territory, Due to Glaciation," *Bull. U. S. Geol. Survey*, No. 40, 8.

[6] F. C. Calkins, *op. cit.*, 31.

[7] *Ibid.*

[8] H. R. Wood, "Glaciation in Western Montana," *Science*, XX (1902), 162.

[9] F. C. Calkins, *op. cit.*, 31, and unpublished field notes.

[10] R. D. Salisbury, *op. cit.*, 723, 724.

[11] H. R. Wood, *loc. cit.*

It appears then that escape of the water through the more northerly passes or by way of the lower Kootenai was effectually blocked by ice-barriers of much more than the necessary height.

One of the very largest of these lobes flowed south through the Purcell trench and dammed the only remaining avenue of escape, the Clark Fork Valley. From 7,300 feet elevation at the 49th parallel the glacier's surface sloped down to about 4,200 feet here, where it forced the lake to seek its outlet.

While the vagueness and close spacing of most of the lower beaches seem to depend on the inconstant level of an ice-dam that formed one wall at least of the outlet, the more prominent ones, indicating constancy of level for a relatively long period, suggest that the outlet may at times have been a col in some opposing spur from the Cœur d'Alene Mountains. Until the ice, by rising, should invade such an outlet, or by sinking below it should capture its flow, the water level would be comparatively stable.

# *Reviews*

*Traité de géographie physique.—Climat—Hydrographie—Relief du sol—Biogéographie.* By Emanuel de Martonne. Paris: Librairie Armand Colin, 1909. 8vo, viii+910 pp., 396 text figs. and maps, 48 phot. plates, 2 colored planispheres.

This work, as stated by one reviewer, is a mine of information with a wealth of useful illustrations. As stated in the author's preface, it aims to put the educated public on the track of important geographic publications, and to give to the specialist a general treatise that will aid in rounding out and properly orienting his special lines of research. Each subject discussed is followed by a full list of recent works bearing upon it, to be found in the French, German, and English languages, and occasional works in other languages. Topographic and other maps of value in illustration of the features discussed are cited by name or number, and include many from the United States as well as from most of the European countries, and a few from Africa and India.

Many of the illustrations are artistic sketches made by the author from nature. Representation in three dimensions is also a notable feature of the illustrations. The wealth of illustrations and of references is combined with a clear and vivid presentation in the text. It will be a useful work for schools as well as for the specialists and the educated public. The author's experience as a teacher as well as a field investigator counts in the preparation of this comprehensive volume. The author's special lines of investigation, glaciers and physiographic features, are handled with exceptional clearness, but the work shows evidence throughout of painstaking collaboration and treatment. As a basis for the discussion of certain subjects the classic works of Hahn, Haug, de Margerie, Angot, and others are freely drawn upon.

The first 72 pages deal with the form and situation of the earth as a planet, and the modes of representing the terrestrial sphere by various projections. The author recommends, and uses in this work, the Mollweide projection for maps of large area, but for topographic maps with a scale of 1:100,000 or less the use of polyconic projections is recommended. He deprecates the use in school atlases and wall maps of the Mercator projection with its exaggeration of polar lands, and urges that the projection be clearly stated on all maps for school use.

The elements of physical geography are discussed very briefly (pp. 73–96). Physical geography is defined as the science of the extent and reciprocal reactions of the phenomena by which the surface activity of the globe is manifested. It deals with an active or living surface, and its particular horizon is at the contact of the gaseous envelope with the solid and liquid parts of the earth's surface. The four main subjects of the work, as stated in the title, are "Climate, or the Physical Geography of the Air," "Hydrography, or the Physical Geography of the Water," "Terrestrial Morphology, or the Physical Geography of the Land," and "Biogeography," which brings out the relation of life to the various physical features.

Under "Climate" (pp. 97–251) are considered three elements, temperature, winds, and degree of humidity, the last named embracing evaporation, humidity, cloudiness, and rainfall. The state of climatological knowledge is set forth by a map (Fig. 38), a revision of one given in Bartholomew's *Physical Atlas*, while the various types of climate are presented on a colored planisphere prepared by the author. This represents for the entire globe 27 types of climate, 9 of which are equatorial and tropical, 5 subtropical, 6 temperate, 3 cold, and 4 desert types. Of the desert types 2 are warm climate (Peruvian and Saharian) and 2 cold climate (Patagonian and Aralian).

Under "Hydrography" (pp. 257–365) the first chapter deals with the ocean, and considers the features of the basins and the temperature and salinity of the water. The second chapter deals with the ocean currents. Then follow in turn chapters on the seas, the lakes, and the streams. Under rivers, attention is given to the relation of the sources to their regimen, and to various other problems of fluvial regimen, climatic, geologic, physiographic, and also the influence of the various types of vegetation.

Under "Terrestrial Morphology" (le relief du sol) the first chapter sets forth the relative value of various classes of topographic maps in giving a knowledge of terrestrial forms. Such maps, supplemented by sketches and views, are the principal sources of knowledge of the earth's features. An analysis is then given of the degree of complexity exhibited by the various forms, and the importance of erosion as a modeling agent is brought out. The several dominating forms of erosion and deposition as distributed on the face of the earth are set forth in a very instructive map (Fig. 172) as follows: (1) mechanical disaggregation with stream transportation, (2) mechanical disaggregation with wind transportation, (3) mechanical disaggregation with accumulation (in interior basins with dry climate), (4) areas of fluvial accumulation, (5) areas of eolian accumulation, (6) loess accumulation, largely eolian, (7) predominating chemical decomposition

with fluvial erosion, (8 and 9) regions of present and past glacial erosion, (10) regions of Quaternary glacial accumulation.

The chapter devoted to the cycle of fluvial erosion is well illustrated by photographs and sketches and sections of maps. Another chapter deals with the influence of the physical properties of the rocks in giving certain features. In this chapter is also discussed the subterranean drainage and karst topography. One chapter each is devoted to the tectonic influences and the volcanic outflows in producing certain features. Following this comes a somewhat detailed discussion of the evolution of drainage systems, in which the nomenclature suggested by Davis is used to some extent. This chapter is exceptionally full of diagrams in three dimensions, prepared by the author, which bring out the stratigraphic conditions as well as the surface features.

A chapter on paleogeography with notions concerning the geologic evolution is perhaps more subject to question than any other part of the volume. The map of the continent of Gondwana (Fig. 271) (modified from Frech), which represents a land area stretching from Australia past Africa to South America in Permo-Carboniferous times, will scarcely be accepted by those who believe in the permanence of the ocean basins. It seems to be based largely upon the distribution of the Glossopteris and kindred plants in Permian time over this wide range of the earth's surface. In addition to this Permo-Carboniferous map of the earth there is one for the Upper Cretaceous (Cénomanien) and the Quaternary; the latter represents also the glaciation. In addition to these are representations of European Miocene and Pliocene distribution of land and sea. The mountain-making movements of Europe, in accordance with ideas of Suess and Marcel-Bertrand, are also brought out in two sketch maps (Figs. 270 and 273).

A chapter is devoted to glaciers and glacial topography (pp. 600–647), which is illustrated by a large number of excellent Alpine photographs and by numerous sketches by the author both of European and American features. These sketches as well as the maps and photographs and descriptions bring out the results of glacial erosion very clearly. The features of accumulation are treated more briefly. A map showing the extent of Quaternary glaciation in the United States (Fig. 298), prepared by Chamberlin in 1894 for Geikie's *Great Ice Age*, should have been replaced by a map showing more recent results of mapping of moraines in the United States. It also erroneously places the Illinoian glaciation in central Iowa.

A chapter is devoted to eolian action and desert forms and another chapter to the coastal topography.

The final subject, "Biogeography," is treated with great fulness (pp. 709–862), and takes up not only the general principles of biogeography, but goes into considerable detail in reference to plant communities in various climatic areas, tropical, subtropical, and temperate, in Alpine regions and Arctic zones, and in desert regions both cold and warm. Under "Zoögeography" the aquatic fauna is discussed in relation to its distribution in deep sea or on continental shelves, and in relation to varying degrees of salinity and warmth of water. The terrestrial fauna is considered in reference to physiographic conditions, food conditions, and climatic conditions.

F. L.

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*Yorkshire Type Ammonites.* Edited by S. S. BUCKMAN. Part I. London, William Wesley & Son.

In this work the editor has undertaken to republish, with illustrations and critical notes, the descriptions of Lias Ammonites from Yorkshire, England, which were originally described by Young and Bird, and by Martin Simpson.

The original publication of Young and Bird, in 1822, appeared under the title *A Geological Survey of the Yorkshire Coast*, "Describing the Strata and Fossils Occurring between the Humber and the Tees, from the German Ocean to the Plain of York, by Rev. George Young, A.M., and John Bird, artist." A second edition, with many alterations from the first, appeared in 1828.

Martin Simpson's first work appeared in 1843 under the title *A Monograph of the Ammonities of the Yorkshire Lias*, "Containing the Specific Characters and Popular Notices of More Than 100 Species; with References to the Particular Beds and Localities Where Each Is to Be Found; Including, Also, the Two Species of Nautilus. Described from Nature, by Martin Simpson, Curator to the Geological and Polytechnic Society of the West Riding of Yorkshire and Late Keeper of the Whitby Museum, Lecturer on Geology, etc." In 1855 a second work by the same author appeared under the title *The Fossils of the Yorkshire Lias; Described from Nature*, "with a Short Outline of the Geology of the Yorkshire Coast. Illustrated with Sections; and Intended as a Guide to Strangers. By M. Simpson, Lecturer on Science, and Curator of Museums." A second edition of this work was published in 1884.

These works, highly important as they are, have never received proper consideration by students of Lias Ammonites, chiefly because they are for

the most part difficult to procure, and are in large measure inaccessible. In the fine discrimination of specific forms Simpson seems to have excelled, but his descriptions are unaccompanied by illustrations, which has rendered them difficult to follow.

In his republication of the descriptions of these forms the editor has had access to the original types, which will be illustrated, and with his critical notes the contribution will be of inestimable value to all students of this highly interesting fauna. For the preparation of such a work as this the editor is the most eminently fitted of any English paleontologist. The work is planned to be complete in about 16 parts of from 12 to 16 plates each. The first and second parts are now published, containing 23 plates with the descriptions of 22 species.

S. W.

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*An Introduction to the Geology of Cape Colony.* By A. W. ROGERS, Sc.D., AND A. L. DU TOIT, A.B. 2d ed. London: Longmans, Green & Co., 1909. Pp. 491, 25 plates, 29 text figures, and a colored map.

The first edition of this work appeared in 1905. During the five years which have passed since its appearance considerable advances have been made in the knowledge of Cape geology, and in the light of this new information, the work has been revised and partially rewritten. The most notable changes occur in those parts of the book which deal with the ancient rocks in the north of Cape Colony, with the Dwyka conglomerate, the correlation of the Karroo system, the intrusive dolerites, and the famous volcanic pipes. The revision also embraces important advances in paleontology. An entirely new chapter on "Economic Geology" has been added, while, in order to keep the book about the same size as before, the less important parts of the first edition have been reduced or omitted.

The chief formations of Cape Colony are the old pre-Cape rocks, the Cape system, Karroo system, and the Cretaceous, and to these the bulk of the volume is devoted, with, however, chapters on the Tertiary-Quaternary deposits, intrusive dolerites, the diamondiferous volcanic pipes, geologic history of the colony, and economic geology. The greatest emphasis has been placed upon the Karroo system which, on account of its peculiar and profoundly significant features, is of special importance to geologists and paleontologists the world over. A chapter on the reptiles of the Karroo is contributed by Professor Broom.

R. T. C.

*History of the Clay Working Industry in the United States.* By HEINRICH RIES, PH.D., AND HENRY LEIGHTON, A.B. Pp. 270, with 8 plates and 3 figures. New York: John Wiley and Sons, 1909.

The arrangement of this admirable book is very simple. In the first part the history of the clay-working industry is treated by products; in the second part the development in each state is taken up in alphabetical order. This manner of treatment necessitates more or less repetition, but it permits the presentation of a more connected chain of events for each district.

A great amount of detailed statistical information has been gathered together and made available for use. Through a historical record of isolated facts, figures, and statistics, the authors of this treatise have such a thorough command of the subject that they have instilled much of their own enthusiasm into its pages.

R. T. C.

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*Norsk geologisk tidsskrift* (*Norwegian Geological Magazine*), *Vol. I.* Kristiania: J. O. Brögger, bookseller, 1910.

The geologists in Norway have formed an association, "Norsk geologisk Forening," in Kristiania and published the first volume of a magazine. The chief contributor is the well-known student of petrography and of the geology of ore bodies, J. Vogt, who writes in German. His important article on anchi-eutectic and anchi-monomineral eruptives is published here.

Th. Vogt (son of J. Vogt) has written a mineralogical article on barytes. A. Hoel communciates new observations on the geology of Spitzbergen (Norwegian with summary in English). The rest of the papers treat of Norwegian geology. All but two have English summaries.

HANS REUSCH